Optoelectronică

Curs 11
2023/2024

Disciplina 2023/2024

- 2C/1L Optoelectronică OPTO
- **Minim 7 prezente curs + laborator**
- Curs – conf. Radu Damian
  - an IV μE
  - Marti 14(:10)–16:00, P8
  - E – 70% din nota (50%+20%)
    - **20% test (VP) la curs**, saptamana 4-6?
  - probleme + (2p prez. curs)
  - toate materialele permise
- Laborator – drd. Stefan Stoica
  - an IV μE
    - Marti 16-20 par
    - Max. 7 prezente
  - L – 30% din nota (+Caiet de laborator)

Cuprins

- **Lumina ca undă electromagnetică*** (ecuaţiile lui Maxwell, ecuaţia undelor, parametrii de propagare)
- **Elemente de fotometrie şi radiometrie*** (mărimi energetice/luminoase)
- **Fibra optică** (realizare, principiu de funcţionare, atenuare, dispersie, banda de frecvenţă)
- **Cabluri optice** (tehnologie, conectori, lipire - splice)
- **Proiectare sistemică a legăturii pe fibra optică** (bandă de frecvenţă, balanţa puterilor)
- **Emiţătoare optice** (LED şi dioda laser - realizare fizică şi functionare)
- **Receptoare optice** (dioda PIN, dioda cu avalanşă - realizare fizică şi functionare)
- **Amplificatoare transimpedanţă** (parametri, scheme tipice, TIA în buclă deschisă, cu reacţie, diferenţiale, control automat al câştigului)
- **Realizarea circuitelor pentru controlul emiţătoarelor optice** (parametri, scheme tipice, controlul puterii, multiplexoare)
- **Dispozitive de captare a energiei solare** (principiu de functionare, utilizare, proiectare)

*** – VP**

Documentatie

Main Courses Master Staff Research Students

Microwave and Optoelectronics Laboratory

We are enlisted in the Telecommunications Department of the Electronics, Telecommunication and Information Technology Faculty (**ETTI**) from the "Gh. Asachi" Technical University (**TUIASI**) in Iasi, Romania

We currently cover inside **ETTI** the fields related to:

- Microwave Circuits and Devices
- Optoelectronics
- Information Technology

Courses

Nr.	Course	Shortcut	Code	Type	Semester	Credits	Weekly	Examination	Link
1	Microwave Devices and Circuits for Radiocommunications	**DCMR**	DOS412T	DOS	7	4	0P,1L,0S,2C	Exam	details
2	Monolithic Microwave Integrated Circuits	**CIMM**	RD.IA.207	DOMS	11	6	1.5L,0S,2C,0P	Exam	details
3	Advanced Techniques in the Design of the Radio-communications Systems	**TAPSR**	RD.IA.103	DIMS	9	6	1.5P,0L,0S,2C	Exam	details
4	Optical Communications	**CO**	DOS409T	DOS	7	5	0P,1L,0S,3C	Colloquium	details
5	Optical Communications	**OC**	EDOS409T	DOS	7	5	0P,1L,0S,3C	Exam	details
6	Satellite Communications	**CS**	RC.IA.104	DIMS	9	6	0L,0S,2C,1.5P	Exam	details
7	Applied Informatics 1	**IA1**	DOF135	DOF	1	4	0P,1L,0S,2C	Verification	details
8	Applied Informatics 1	**AI1**	EDOF135	DOF	1	4	0P,1L,0S,2C	Verification	details
9	Databases, Web Programming and Interfacing	**DWPI**	ITT.IA.601	DIS	11	5	1P,1L,0.25S,1C	Verification	details
10	Web Applications Design	**PAW**	RC.IA.108	DIMS	10	5	1L,0S,1.5C,1P	Exam	details
11	Optoelectronics	**OPTO**	DID405M	DID	8	4	0P,1L,0S,2C	Colloquium	details
12	Microwave Devices and Circuits for Radiocommunications (English)	**MDCR**	EDOS412T	DOS	8	4	0P,1L,0S,2C	Exam	details

Documentatie

- RF-OPTO
  - http://rf-opto.etti.tuiasi.ro
- Fotografie
  - “examen” online
  - necesara la laborator/curs

LED

Dioda electroluminescenta

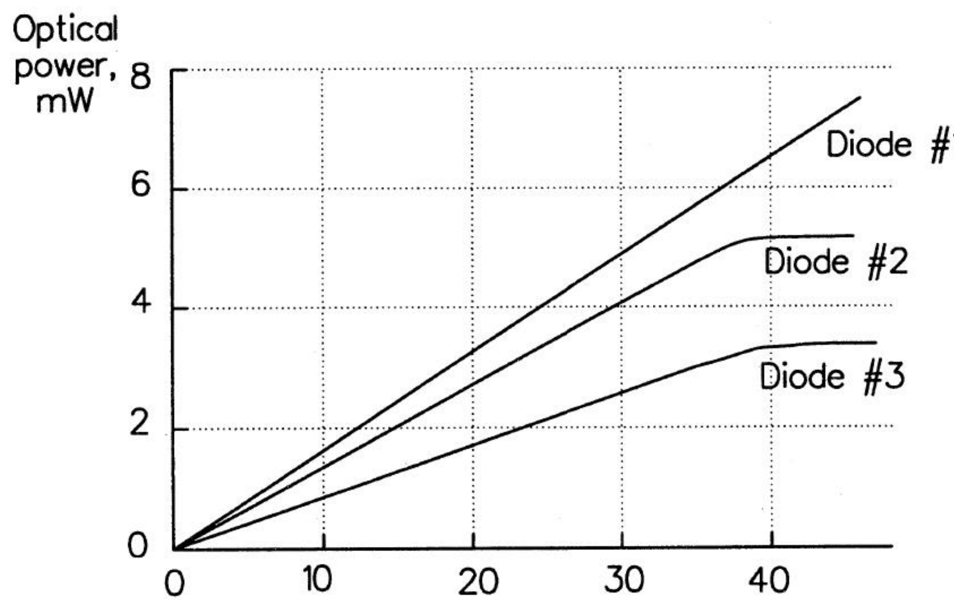
Capitolul 7

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

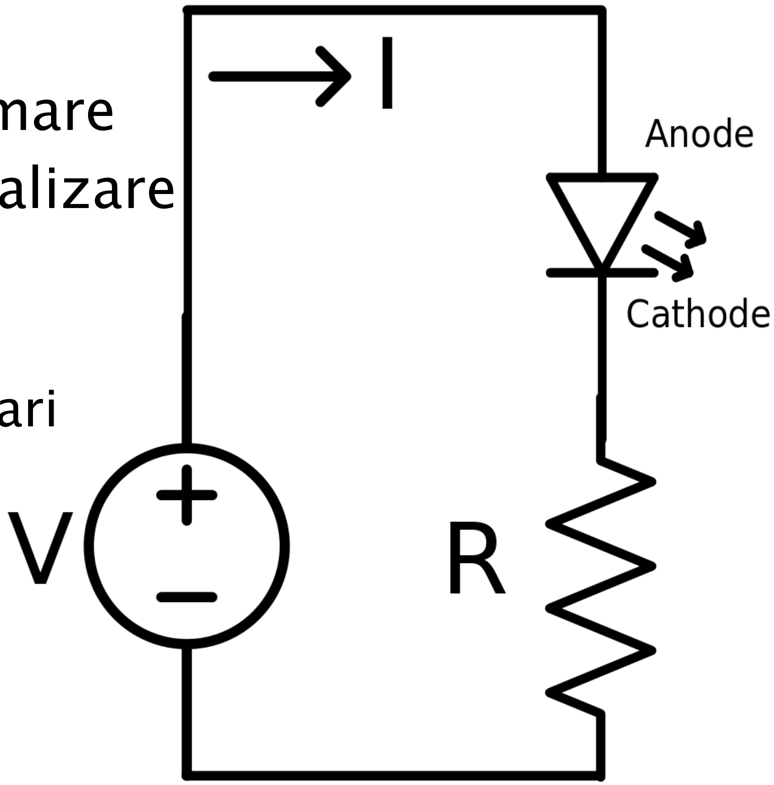


Control static LED

- Cea mai simpla schema de control: un rezistor in serie cu LED
  - **Atentie!** Tensiunea directa poate varia semnificativ (>>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

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

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



Control static LED

Ultra Bright LED Lamps Round Types

Package	Part No.	Chip: Material Emitted Color	Chip: Peak Wave Length p(nm)	Chip: Dominant Wave Length λd(nm)	Absolute Maximum Ratings: Δλ (nm)	Absolute Maximum Ratings: Pd (mw)	Absolute Maximum Ratings: If (mA)	Absolute Maximum Ratings: Peak (mA)	Electro-optical Data(At 20mA): Vf (V) Typ.	Electro-optical Data(At 20mA): Vf (V) Max	Electro-optical Data(At 20mA): Iv (mcd) Typ.	Viewing Angle 2θ 1/2 (deg)	Drawing No.
T-1 Standard 1.0" Lead 3φ Water Clear	BL-BF43V1	GaAlAs/ DDH Super Red	660	643±5	20	80	30	150	2.0	2.6	700	25	L-001
	BL-BG33V1	InGaAlP/ Yellow Green	573	571±5	15	100	30	150	2.2	2.6	700	25	
	BL-BG43V1	InGaN/SiC/ Bluish Green	505	505±5	30	120	30	150	3.5	4.0	3500	24	
	BL-BG63V1	InGaN/SiC/ Green	525	525±5	35	120	30	150	3.5	4.0	4000	24	
	BL-BJ23V1	InGaAlP/ Super Orange	620	615±5	17	100	30	150	2.2	2.6	1700	25	
	BL-BJ33V1	InGaAlP/ Super Orange	630	625±5	17	100	30	150	2.2	2.6	1100	25	
	BL-BJ63V1	InGaAlP/ Super Orange	610	605±5	17	100	30	150	2.2	2.6	1500	25	
	BL-BJ73V1	InGaAlP/ Super Orange	630	625±5	17	100	30	150	2.2	2.6	1500	25	
	BL-BJH3V1	InGaAlP/ Super Orange	630	625±5	17	100	30	150	2.2	2.6	2500	[illegible]	
	BL-BJG3V1	InGaAlP/ Super Orange	630	625±5	17	100	30	150	2.2	2.6	3000	25	
	BL-BK43V1	InGaAlP/ Super Yellow	590	587±5	15	100	30	150	2.2	2.6	1600	25	
	BL-BK53V1	InGaAlP/ Super Yellow	595	594±5	15	100	30	150	2.2	2.6	1500	25	
	BL-BK73V1	InGaAlP/ Super Yellow	595	594±5	15	100	30	150	2.2	2.6	[illegible]	25	
	BL-BK83V1	InGaAlP/ Super Yellow	590	587±5	15	100	30	150	2.2	2.6	[illegible]	25	
	BL-BKH3V1	InGaAlP/ Super Yellow	590	587±5	15	100	30	150	2.2	2.6	[illegible]	25	
	BL-BKG3V1	InGaAlP/ Super Yellow	590	587±5	15	100	30	150	2.2	2.6	3000	25	
	BL-BF43V4V	GaAlAs/ DDH Super Red	660	643±5	20	80	30	150	[illegible]	2.6	1200	15	
	BL-BG33V4V	InGaAlP/ Yellow Green	573	571±5	15	100	30	150	2.2	2.6	1100	[illegible]	
	BL-BG43V4V	InGaN/SiC/ Bluish Green	505	505±5	30	120	30	150	3.5	4.0	6000	[illegible]	
	BL-BG63V4V	InGaN/SiC/ Green	525	525±5	35	120	30	150	3.5	4.0	5600	[illegible]	

3.5	4.0	3500
3.5	4.0	4000
2.2	2.6	1700
2.2	2.6	1100

♦Electro-Optical Characteristics

Item	Symbol	Condition	Minimum	Typical	Maximum	Unit
Forward Voltage	V_F	I_F = 240 mA		19.0		V
Brightness	I_V	I_F = 240 mA		13		cd
Total Radiated Power	P_O	I_F = 240 mA		60		mW

Dioda Laser

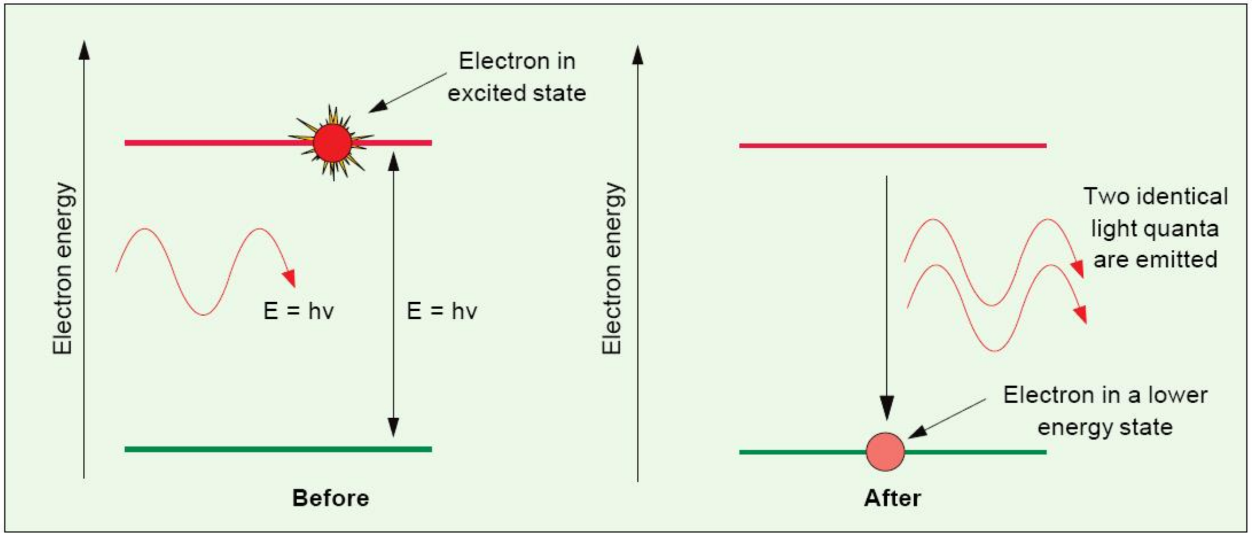
Capitolul 8

Cuprins

- **Lumina ca undă electromagnetică** (ecuaţiile lui Maxwell, ecuaţia undelor, parametrii de propagare)
- **Elemente de fotometrie şi radiometrie** (mărimi energetice/luminoase)
- **Fibra optică** (realizare, principiu de funcţionare, atenuare, dispersie, banda de frecvenţă)
- **Cabluri optice** (tehnologie, conectori, lipire - splice)
- **Proiectare sistemică a legăturii pe fibra optică** (bandă de frecvenţă, balanţa puterilor)
- **Emiţătoare optice** (LED şi dioda laser - realizare fizică şi functionare)
- **Receptoare optice** (dioda PIN, dioda cu avalanşă - realizare fizică şi functionare)
- **Amplificatoare transimpedanţă** (parametri, scheme tipice, TIA în buclă deschisă, cu reacţie, diferenţiale, control automat al câştigului)
- **Realizarea circuitelor pentru controlul emiţătoarelor optice (**parametri, scheme tipice, controlul puterii, multiplexoare**)**
- **Dispozitive de captare a energiei solare** (principiu de functionare, utilizare, proiectare)

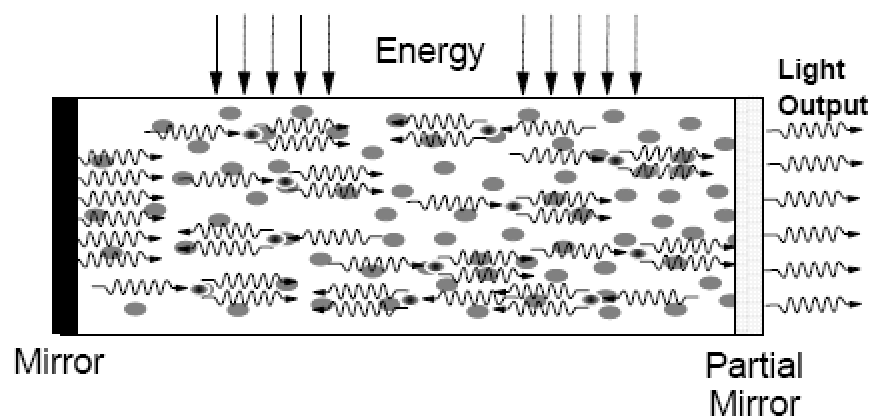
Dioda LASER – Principiu de operare

- 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

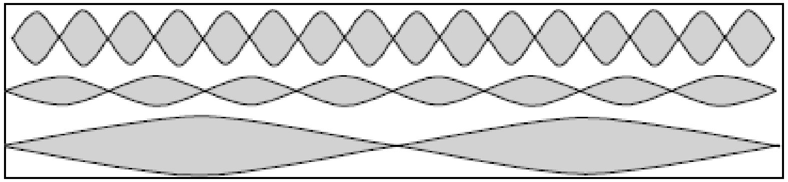


Dioda LASER – Principiu de realizare

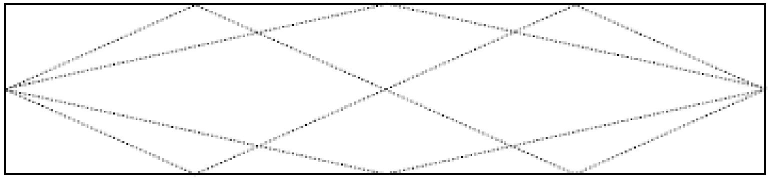
- Pentru ca emisia stimulata sa apara, fotonii emisi trebuie sa ramana in contact cu materialul o perioada mai mare de timp – 2 oglinzi necesare
- Pentru a permite extragerea radiatiei e necesar ca una din oglinzi sa fie partial reflectanta



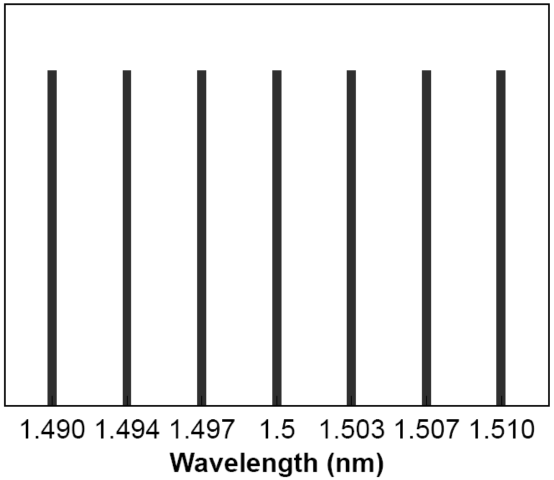
Spectrul diodei LASER



Longitudinal Modes



Lateral Modes



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

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

Caracteristica de raspuns DL

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

$I < I_{th}$ regim LED

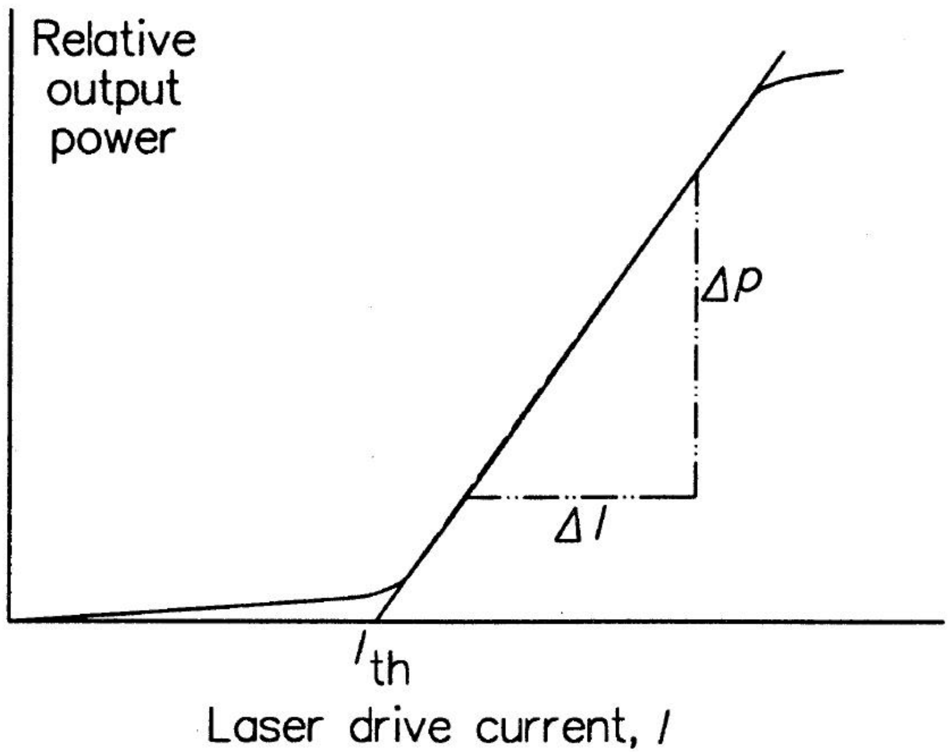
ineficient!, $P_o \cong 0$

$I > I_{th}$ regim LASER

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

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

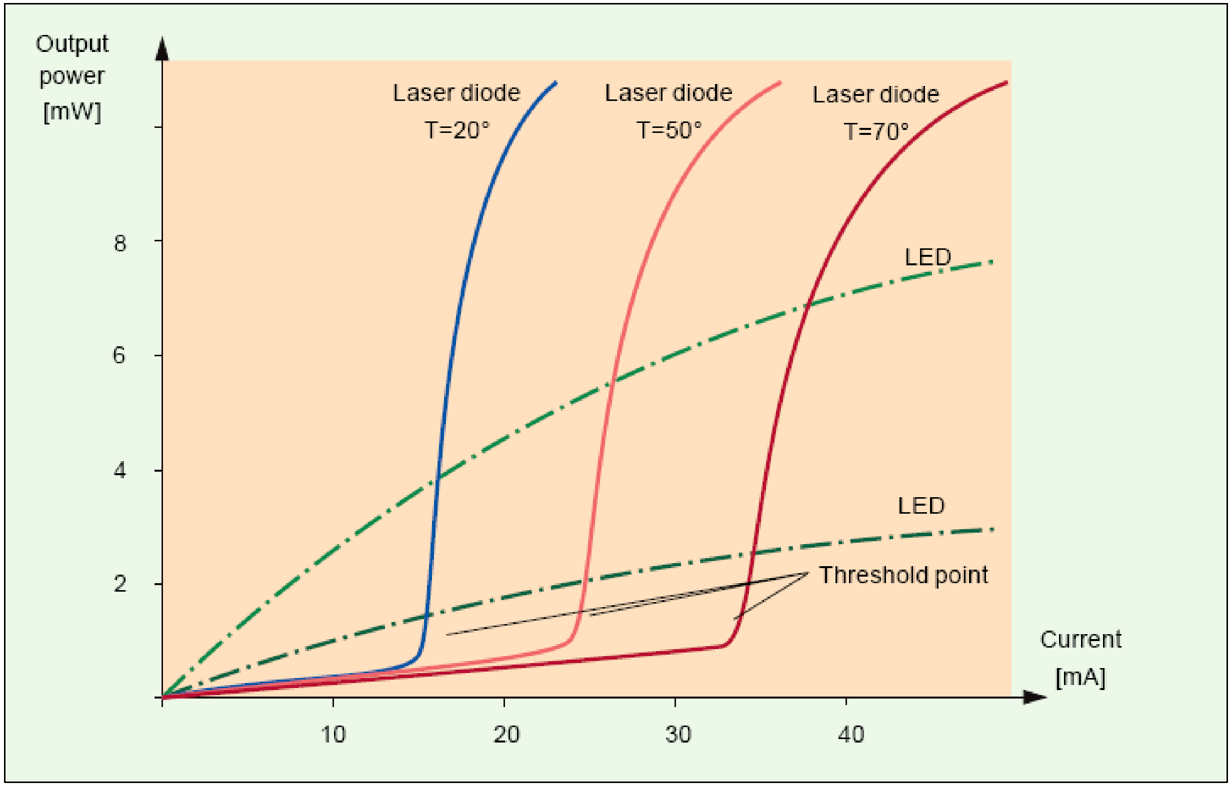
Apare saturare la nivele mari de curent



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

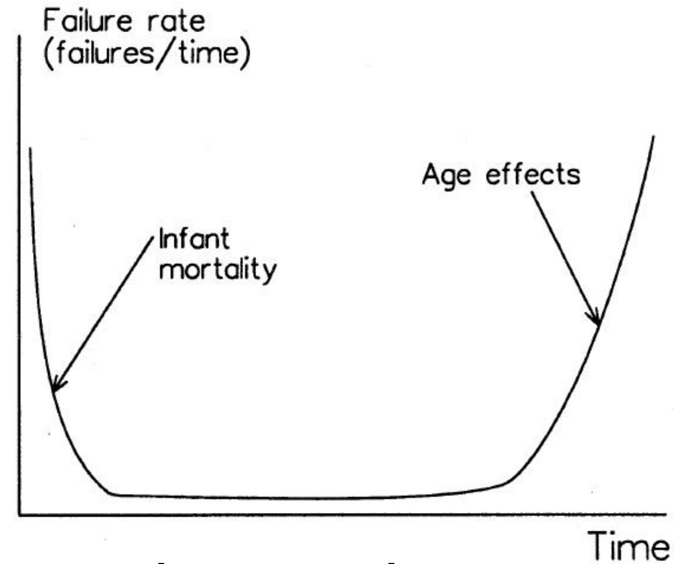
Degradare in timp

- 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 $2000 \div 5000 A/cm^2$
  - densitati de putere optica: $10^5 \div 10^6 W/cm^3$
- Diverse definitii ale timpului de viata fac comparatiile dificile

Degradare in timp



- Cresterea curentului duce la scaderea duratei de viata

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

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

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

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

Parametri

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

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

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

Eficienta

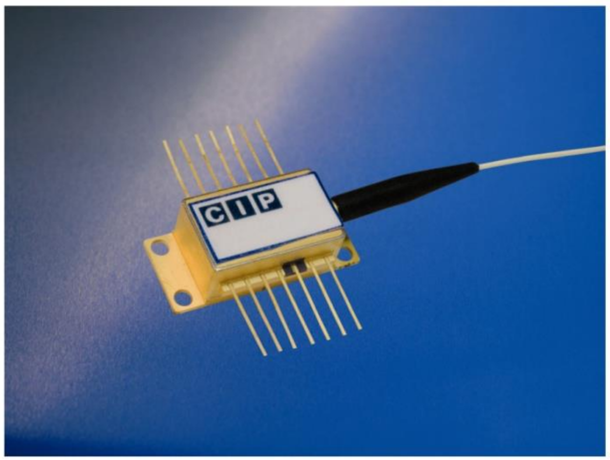
- eficienta de conversie electro-optic (randament)

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

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

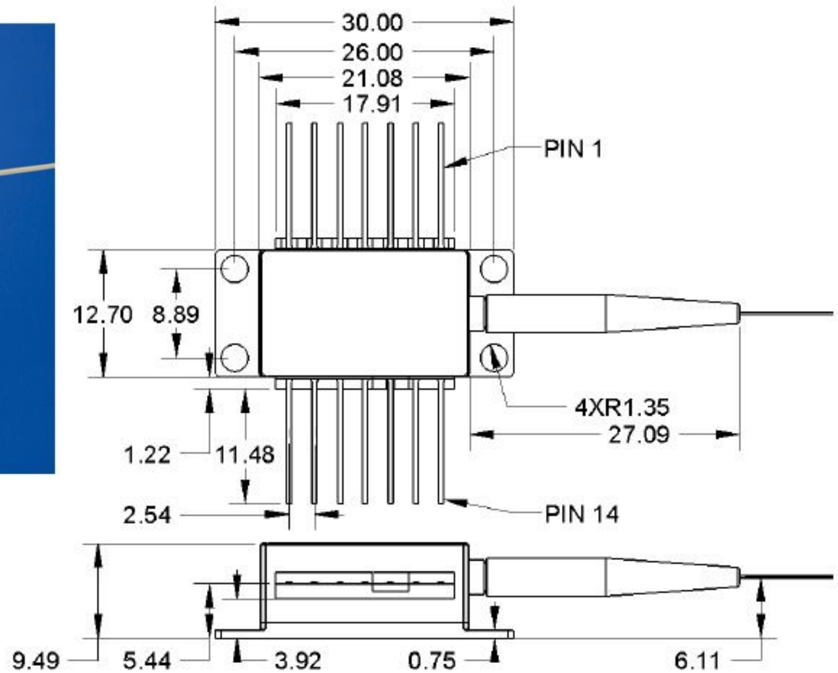
$$\eta = \frac{n_f}{n_e} \qquad \eta = \frac{\Delta P / h\nu}{\Delta I / e} = r \cdot \frac{e}{h\nu}$$

1550nm DFB Laser



Mechanical Drawing

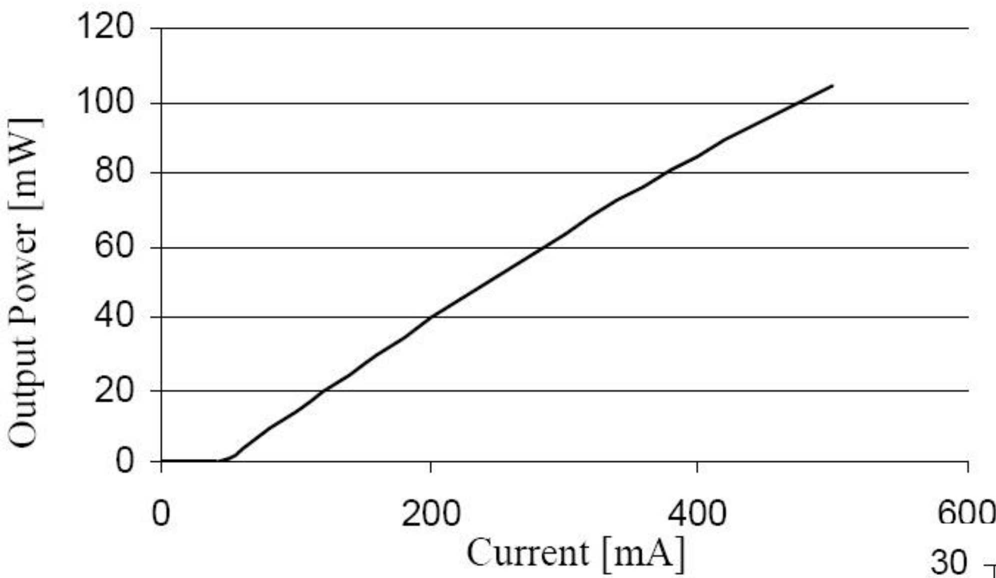
All units in mm

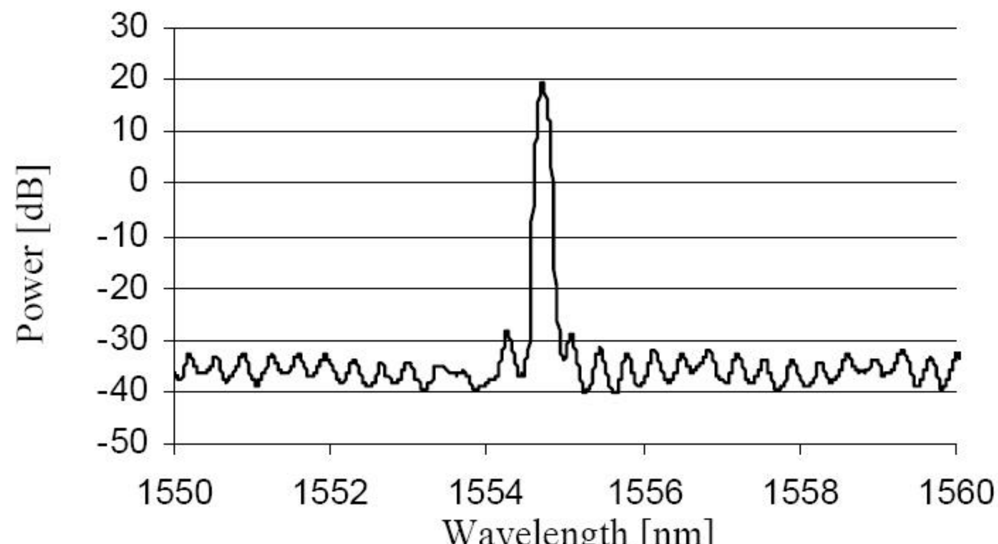


Pin out

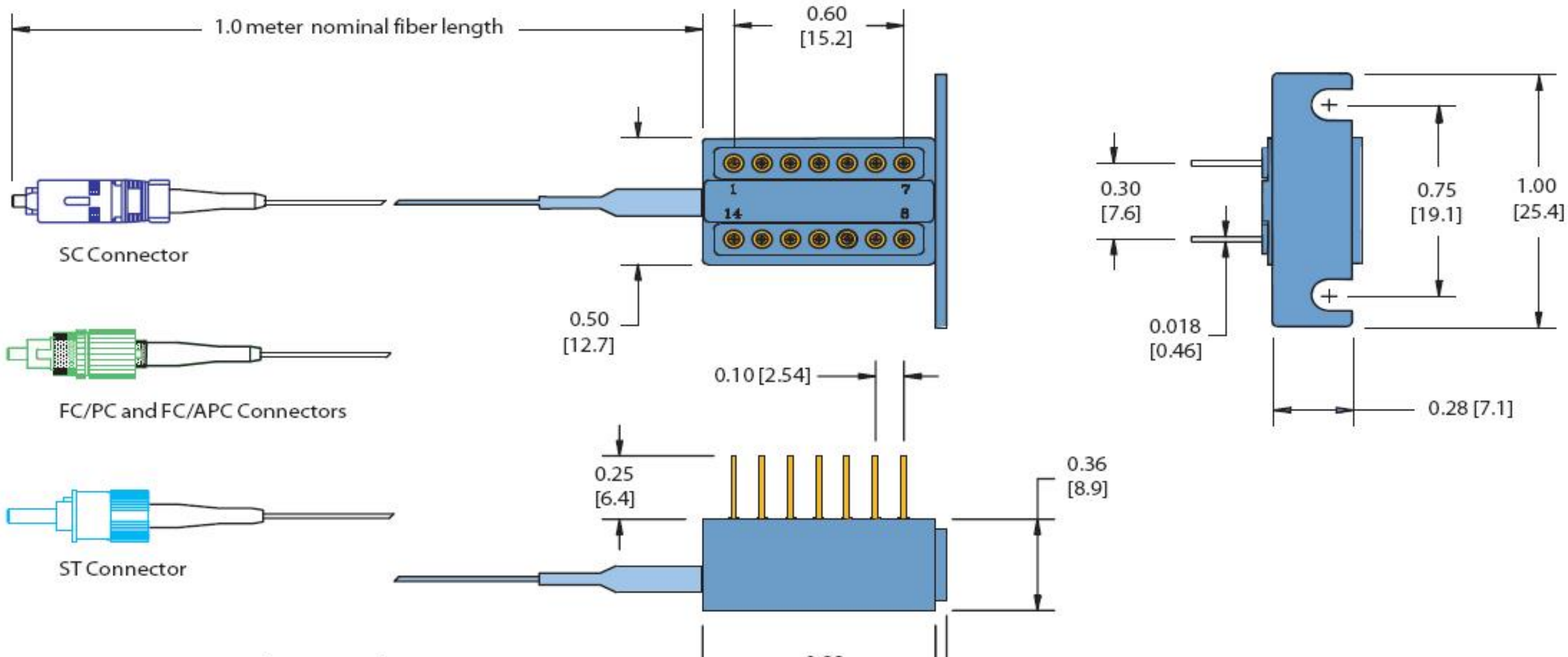
Pin	Description
1	Thermistor
2	Thermistor
3	Laser Cathode (Bias)
4	Monitor PD Anode
5	Monitor PD Cathode
6	TEC +
7	TEC -
8	Case GND, Laser Anode
9	Case GND, Laser Anode
10	Case GND, Laser Anode
11	Case GND, Laser Anode
12	Laser Cathode (modulation)
13	Case GND, Laser Anode
14	Case GND, Laser Anode

1550nm DFB Laser

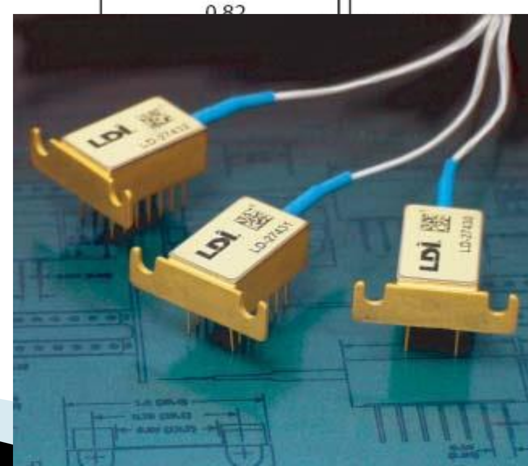


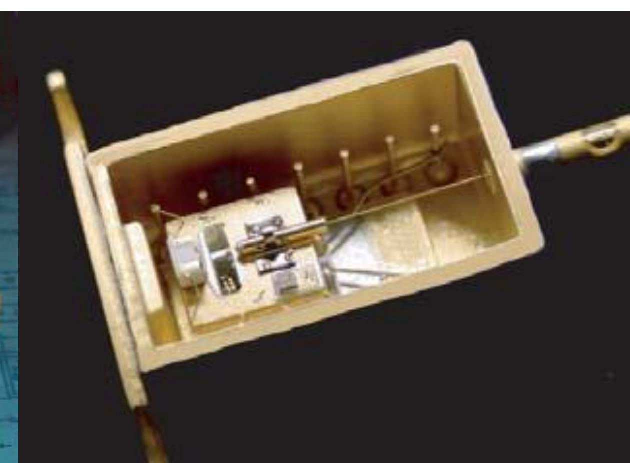


1550nm MQW Laser

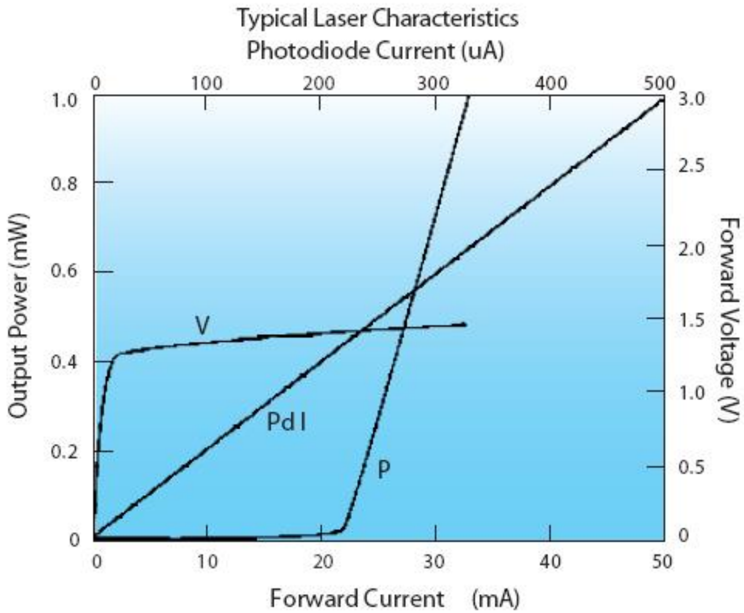


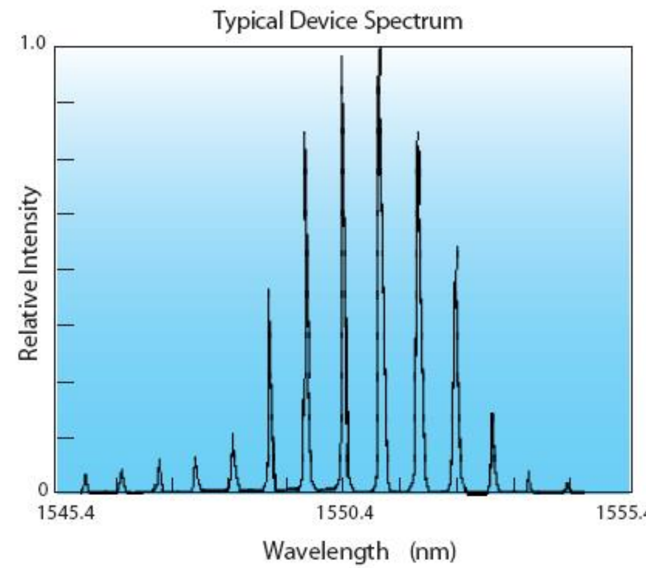
Note: Connectors are not drawn to scale.





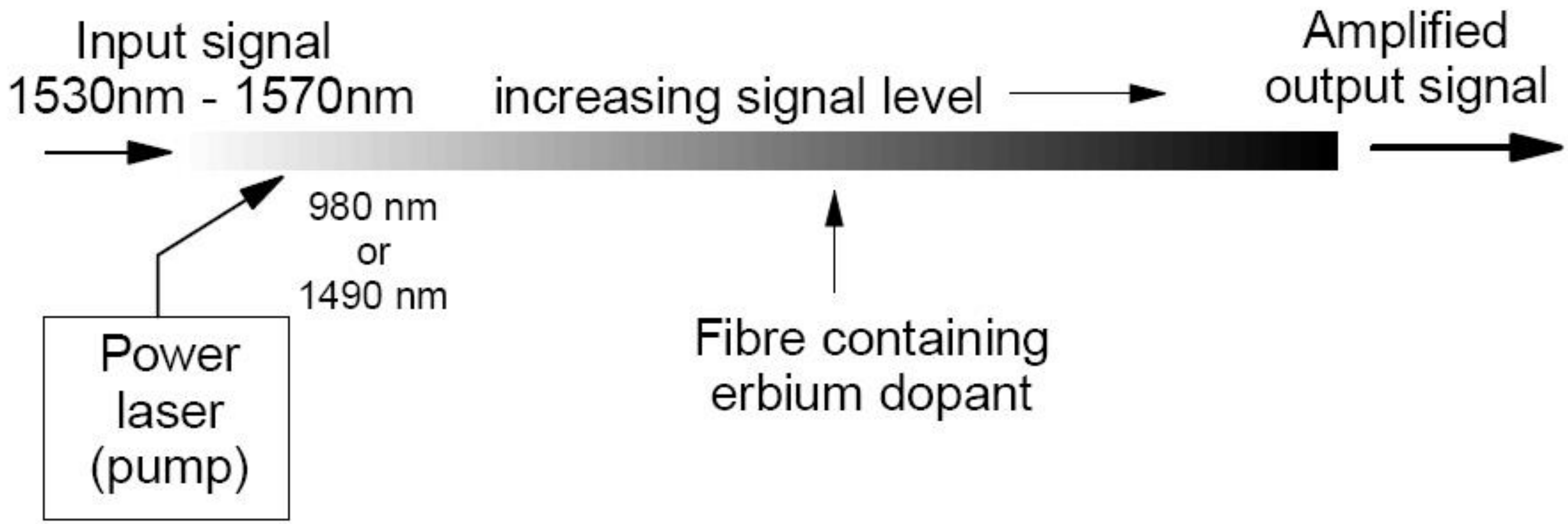
1550nm MQW Laser



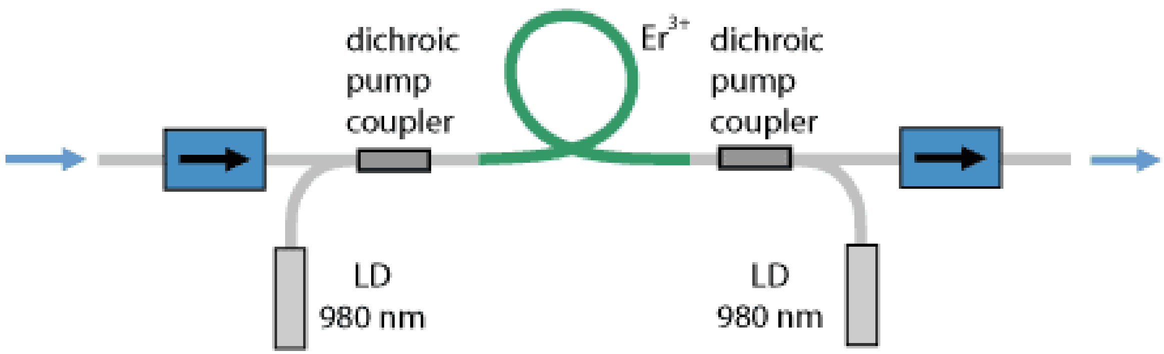


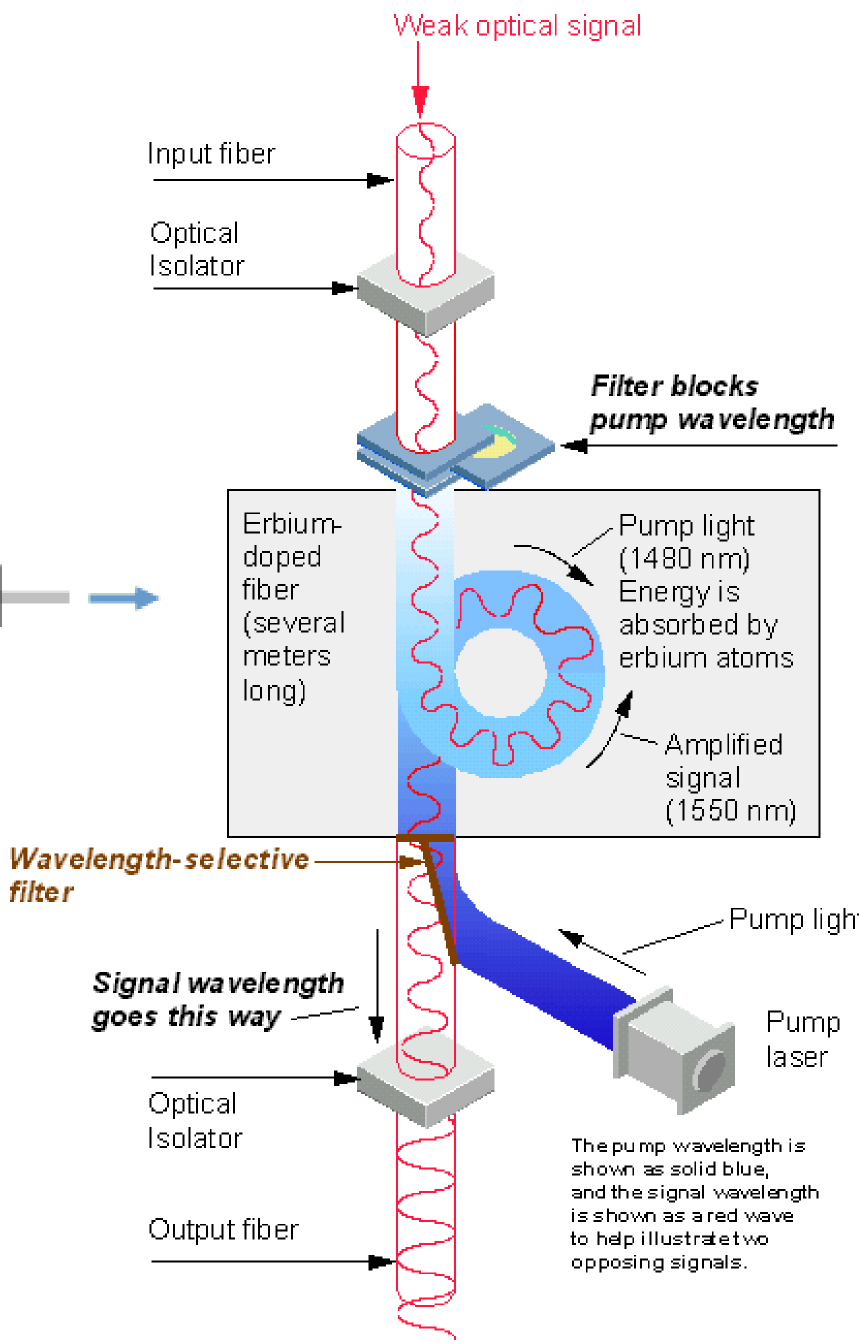
EDFA

- Erbium Dopped Fiber Amplifier

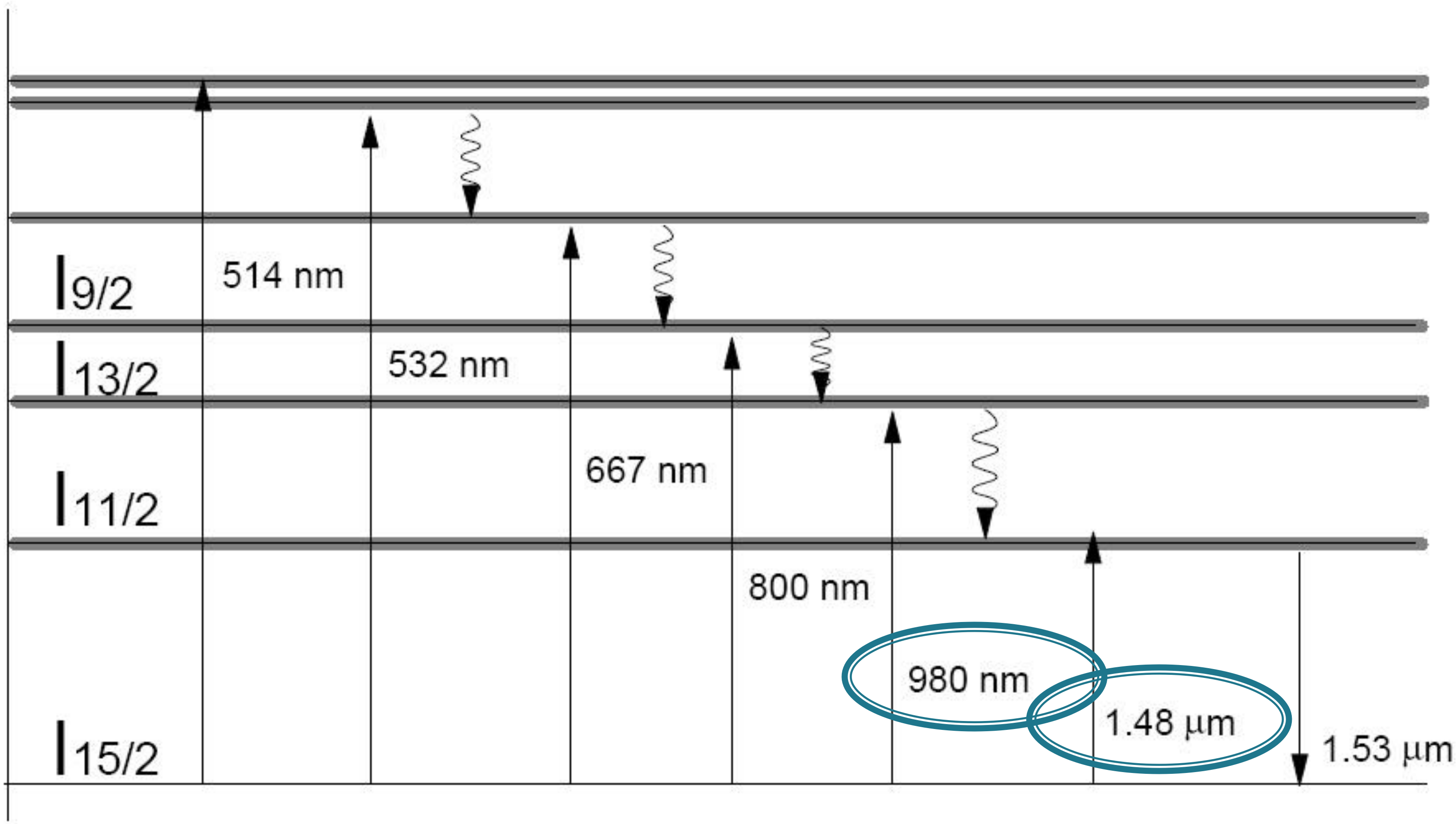


EDFA


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


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

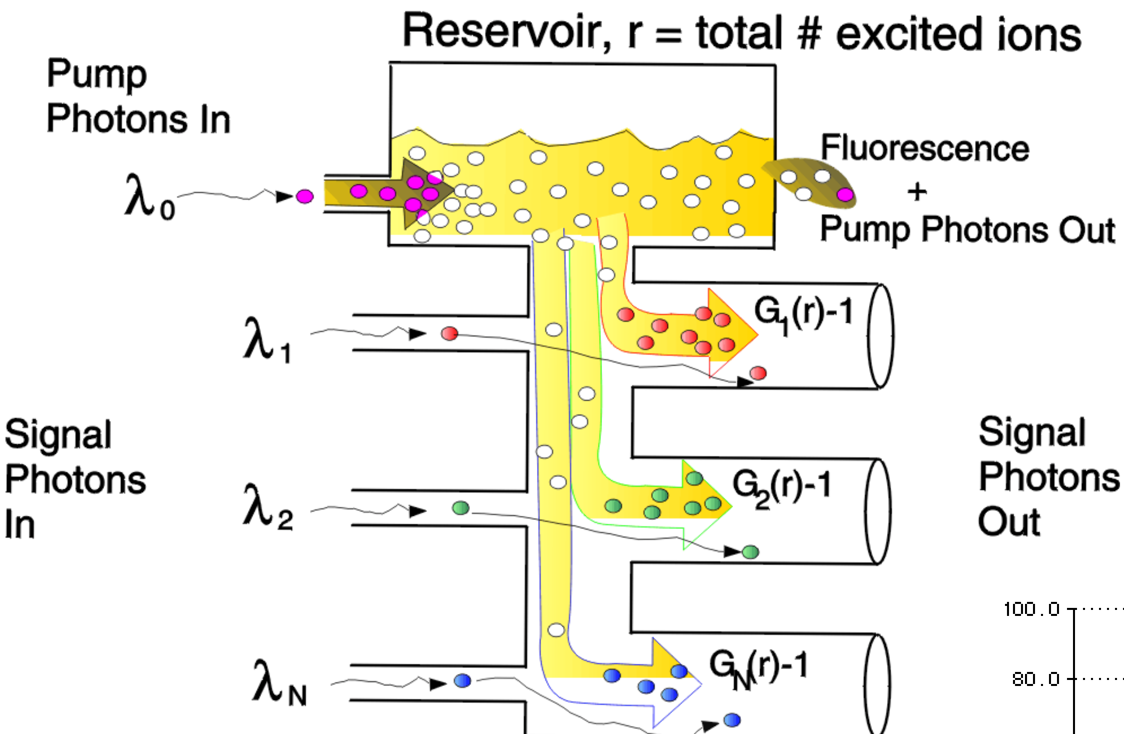
EDFA – Erbium

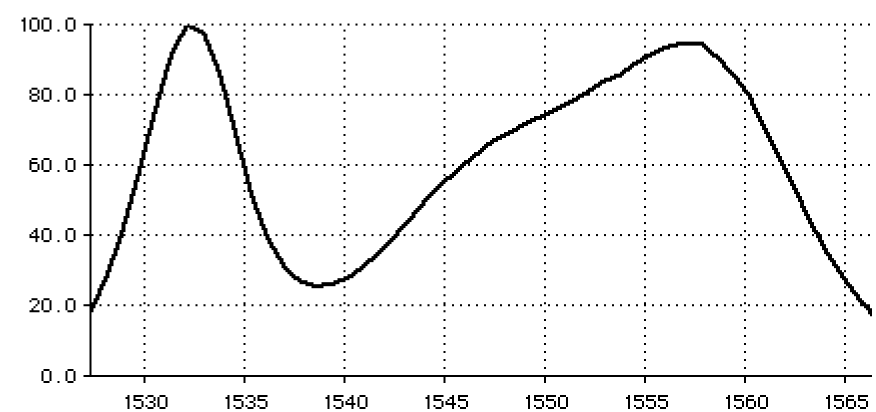


I9/2
514 nm
I13/2
532 nm
667 nm
I11/2
800 nm
980 nm
1.48 μm
I15/2
1.53 μm

EDFA

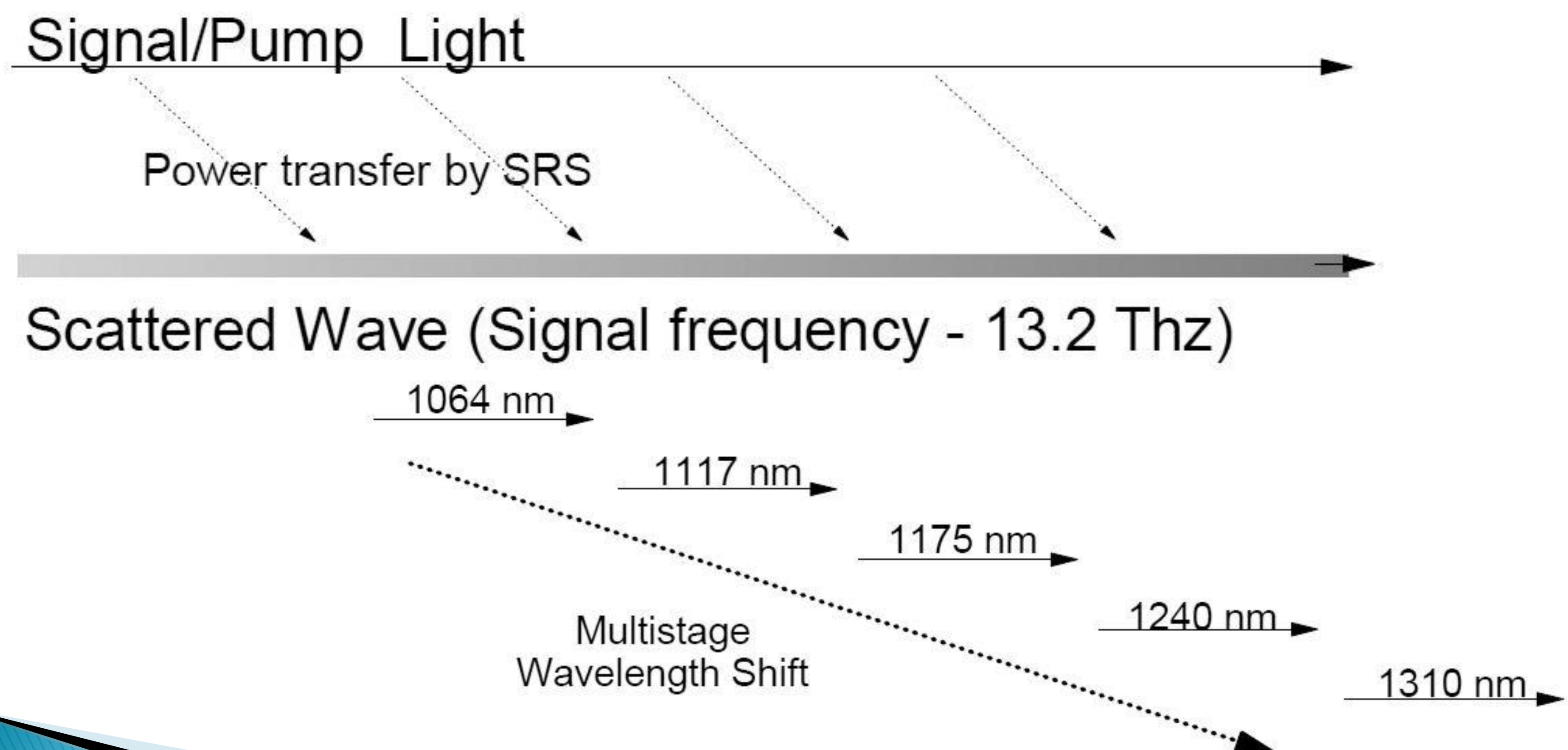
How to think of an EDFA



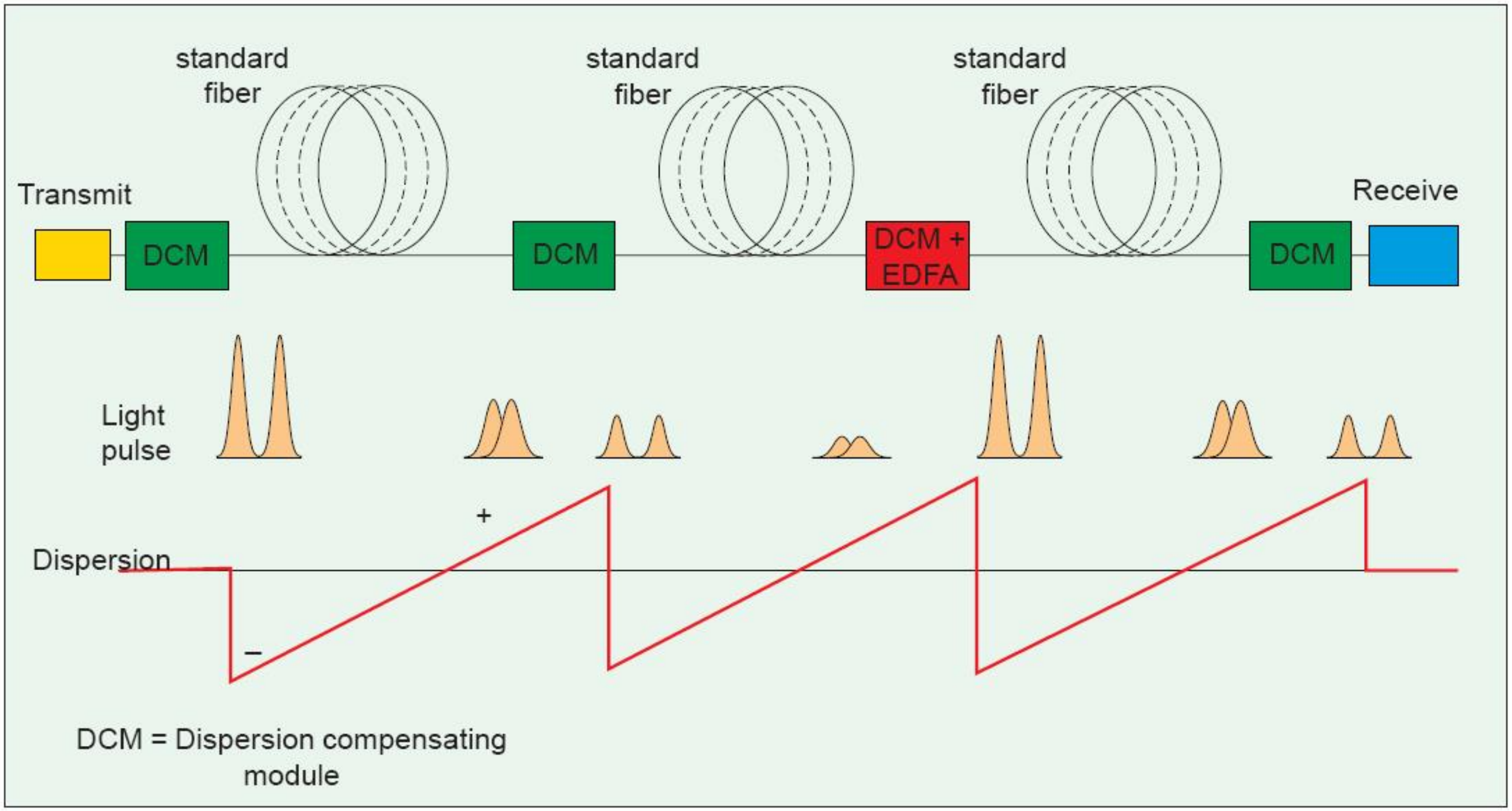


Amplificator cu efect Raman

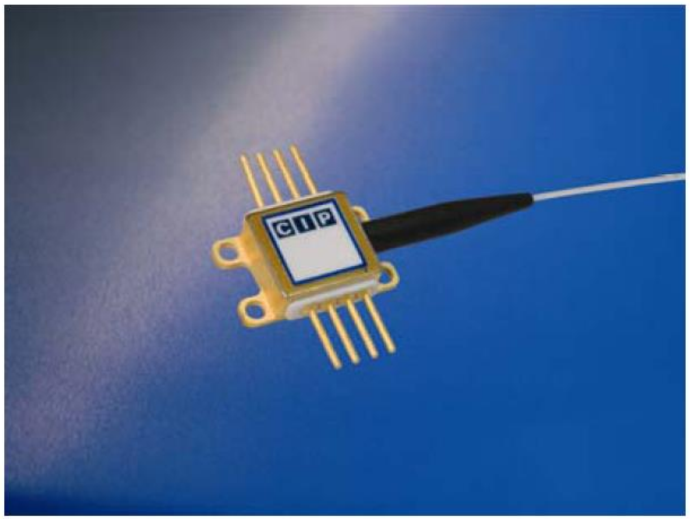
- Bazat pe efect Raman

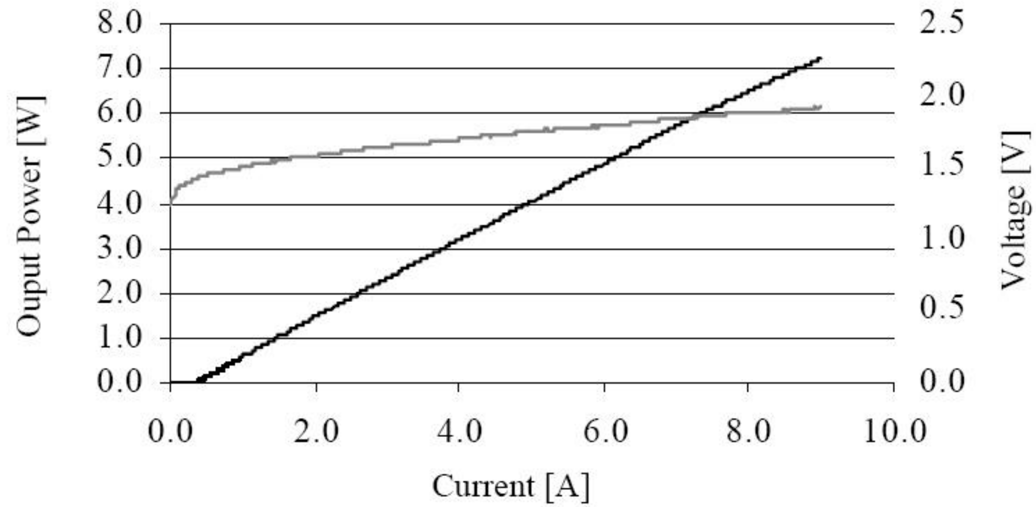


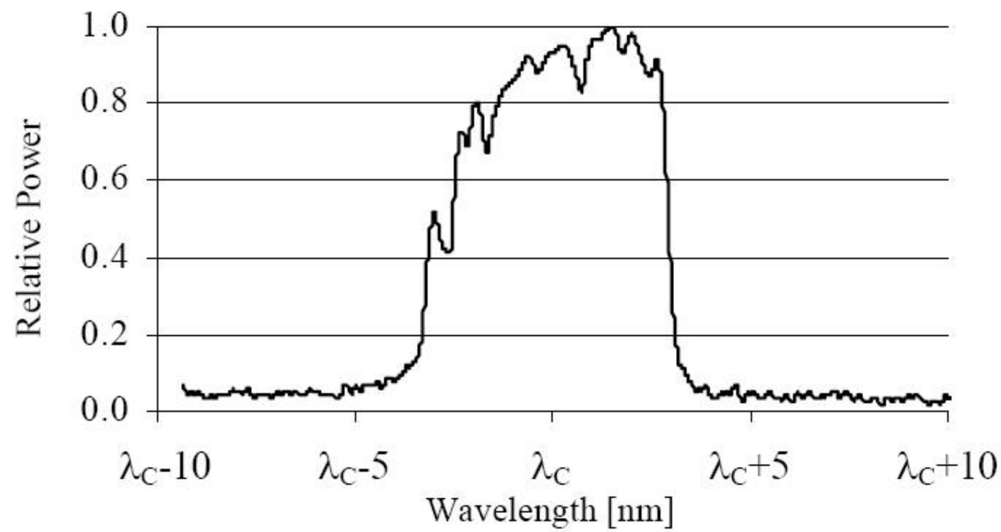
Utilizare amplificatoare optice



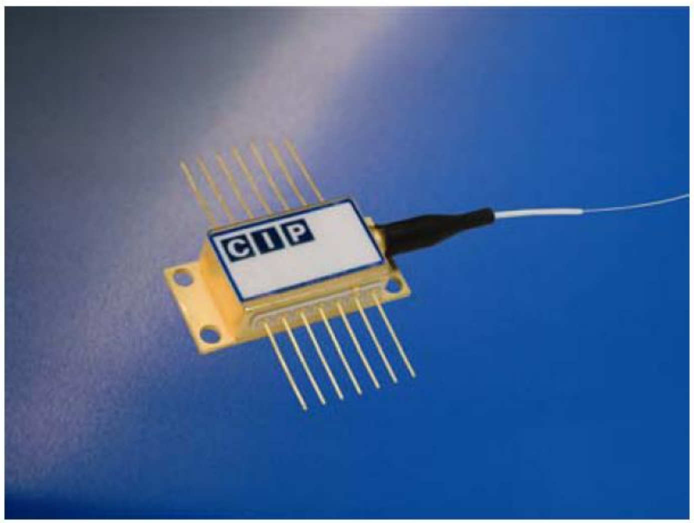
7W 980 nm Multimode Pump Laser

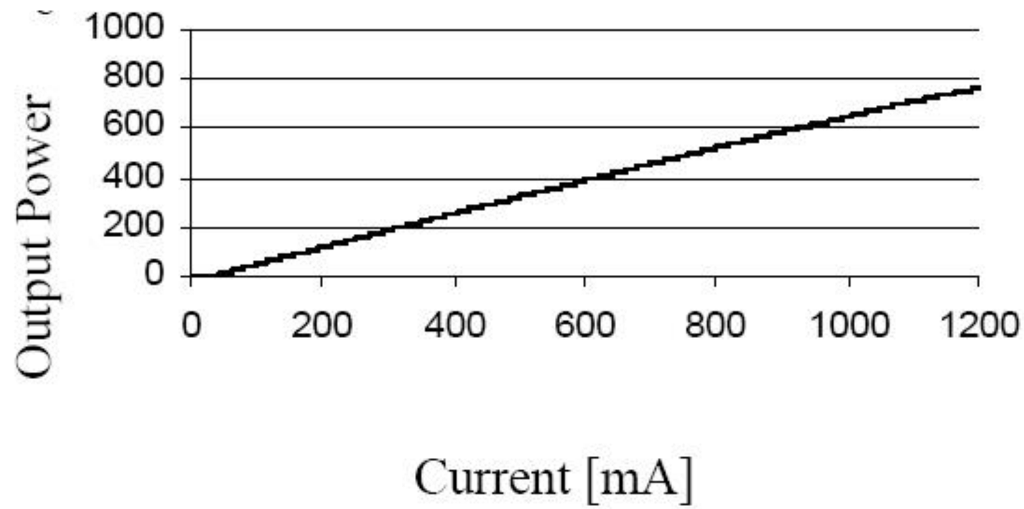


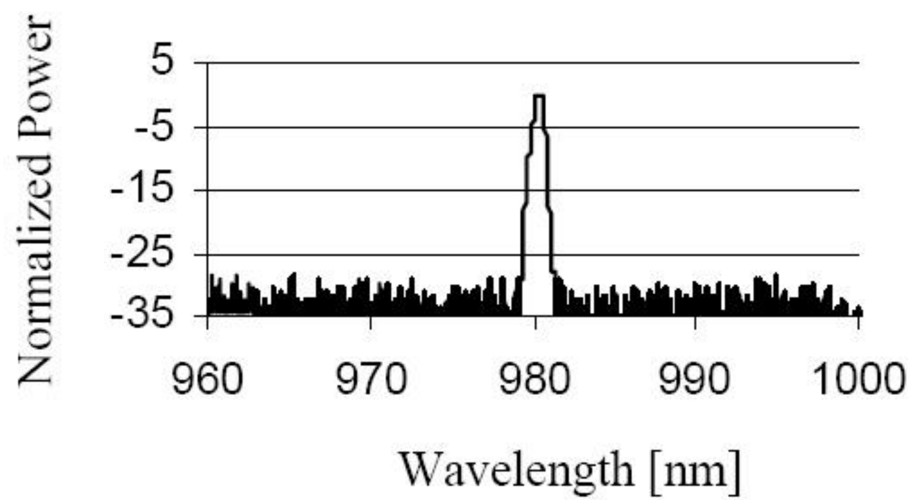




600mW 980 nm Singlemode Pump Laser

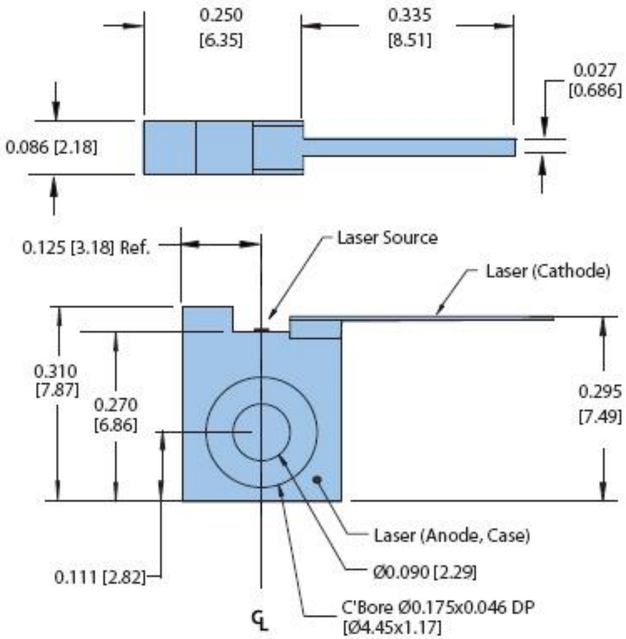




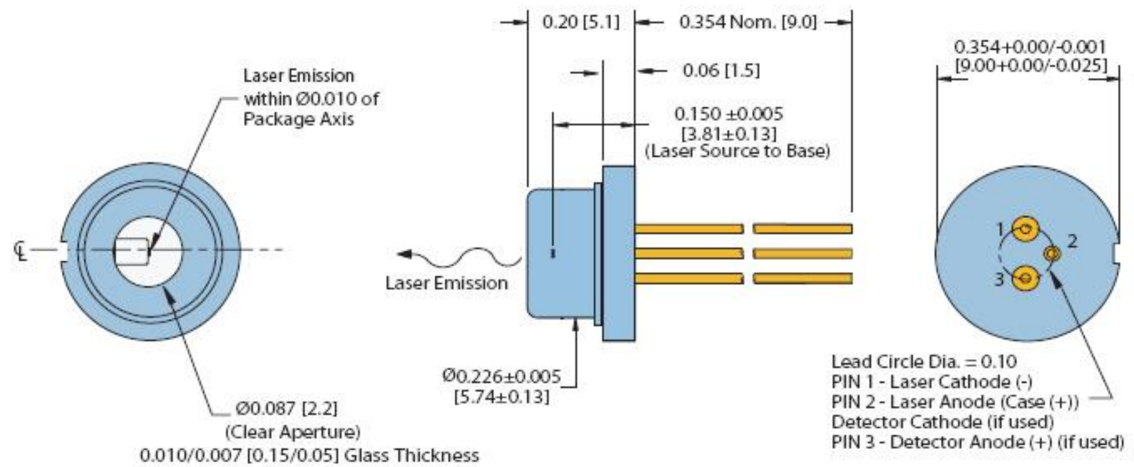


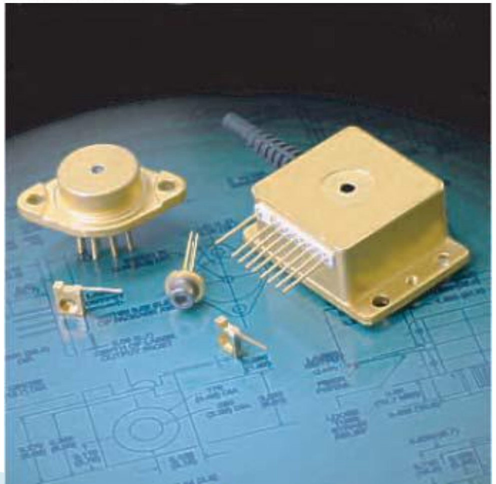
6 W, CW, 800nm

C-Mount Package

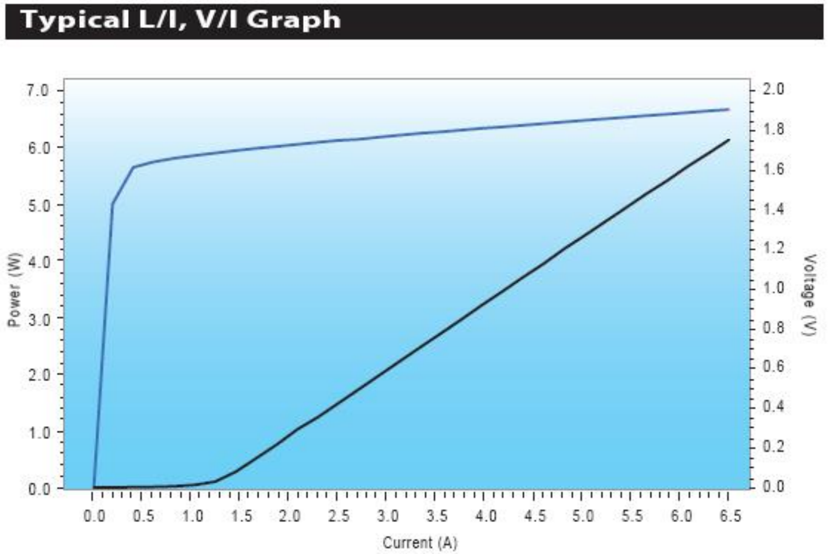


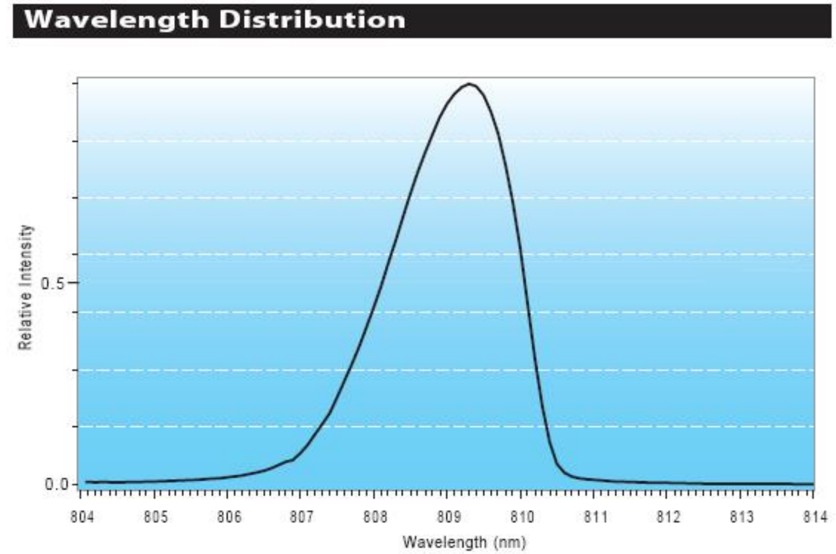
9mm Package

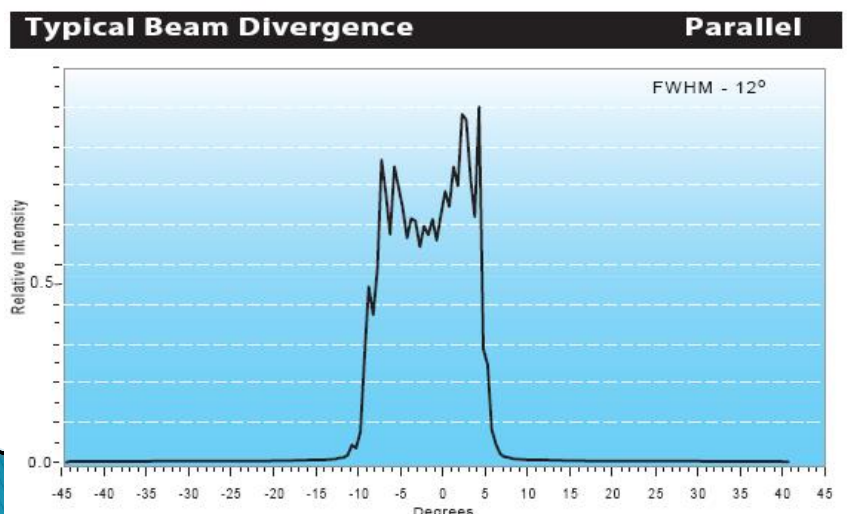


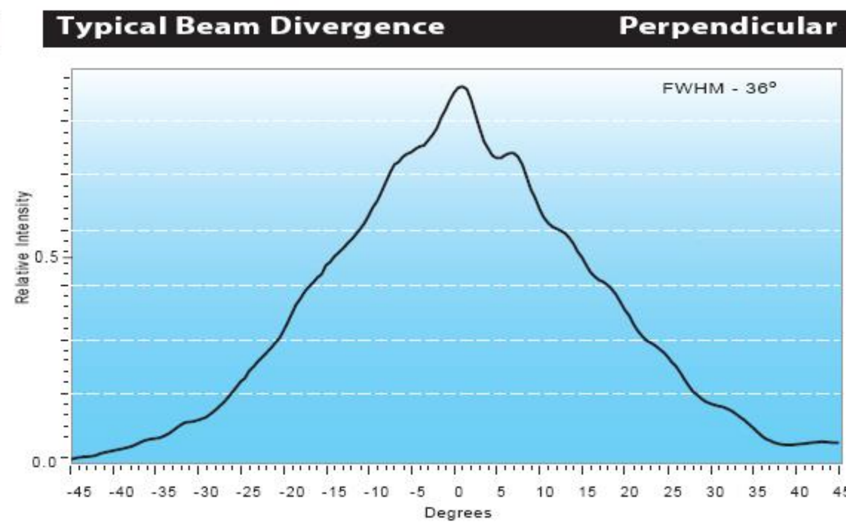


6 W, CW, 800nm

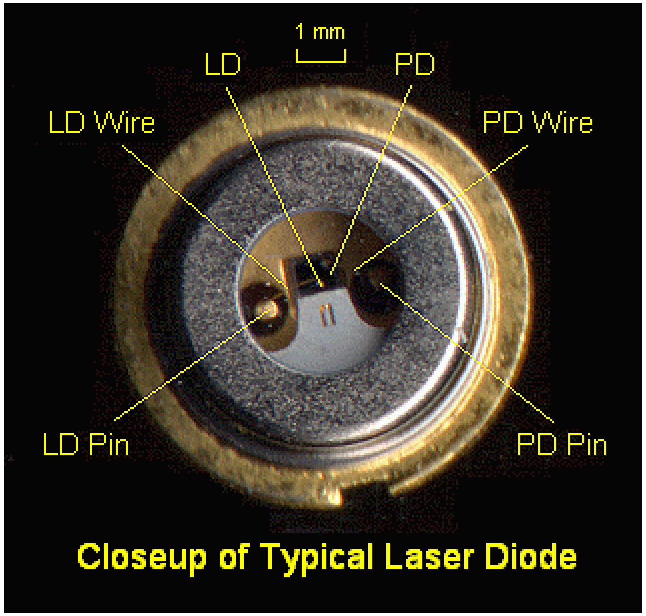

Typical L/I, V/I Graph
Power (W)
Voltage (V)
Current (A)

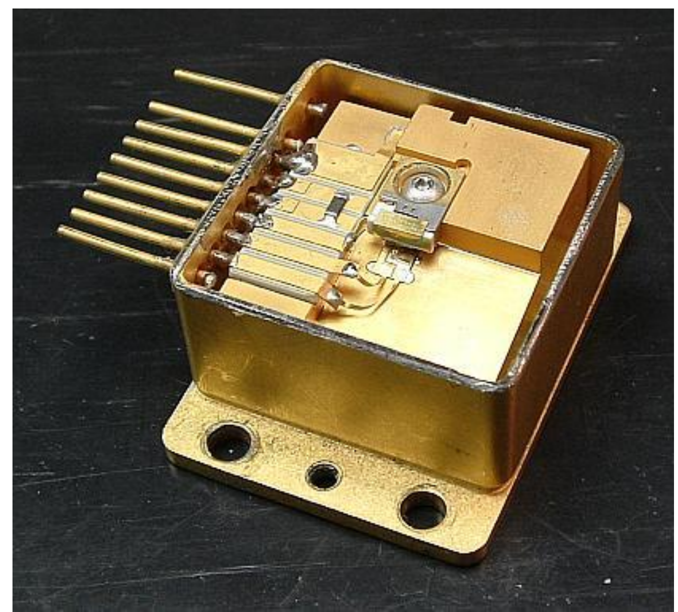

Wavelength Distribution
Relative Intensity
Wavelength (nm)


Typical Beam Divergence
Parallel
FWHM - 12°
Relative Intensity
Degrees


Typical Beam Divergence
Perpendicular
FWHM - 36°
Relative Intensity
Degrees

CW Laser, 650 nm

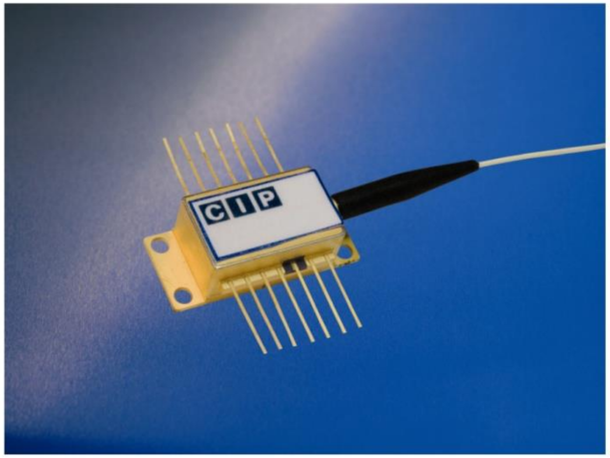




Lungimi de unda

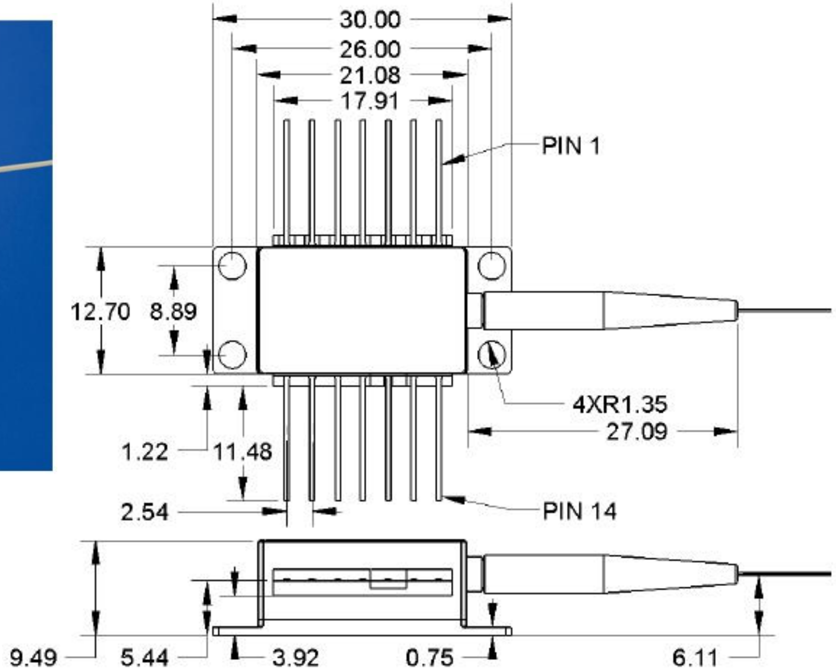
- **405 nm** – InGaN blue-violet laser, in Blu-ray Disc and HD DVD drives
- **445–465 nm** – InGaN blue laser multimode diode recently introduced (2010) for use in mercury-free high-brightness data projectors
- **510–525 nm** – Green diodes recently (2010) developed by Nichia and OSRAM for laser projectors.
- **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: O_2
- **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: NH_3
- **1,550 nm** – InGaAsP, InGaAsNSb fiber-optic communication
- **1,625 nm** – InGaAsP fiber-optic communication, service channel
- **1,654 nm** – InGaAsP gas sensing: CH_4
- **1,877 nm** – GaInAsSb gas sensing: H_2O
- **2,004 nm** – GaInAsSb gas sensing: CO_2
- **2,330 nm** – GaInAsSb gas sensing: CO
- **2,680 nm** – GaInAsSb gas sensing: CO_2
- **3,030 nm** – GaInAsSb gas sensing: C_2H_2
- **3,330 nm** – GaInAsSb gas sensing: CH_4

1550nm DFB Laser



Mechanical Drawing

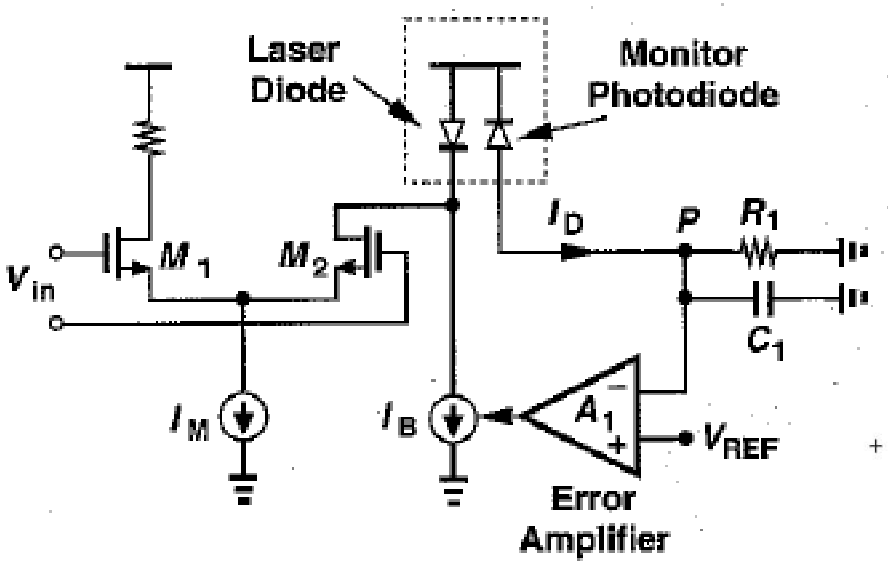
All units in mm



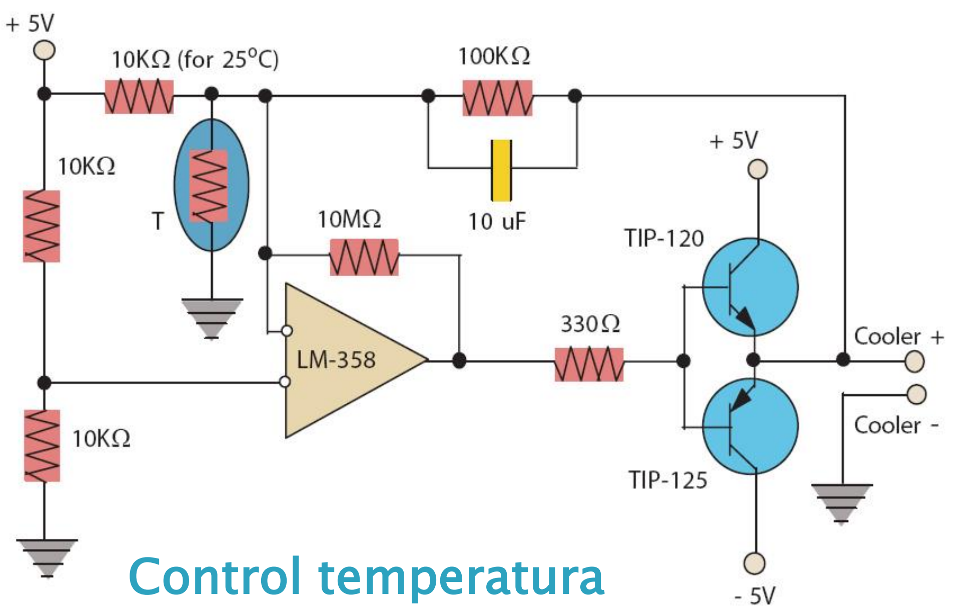
Pin out

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



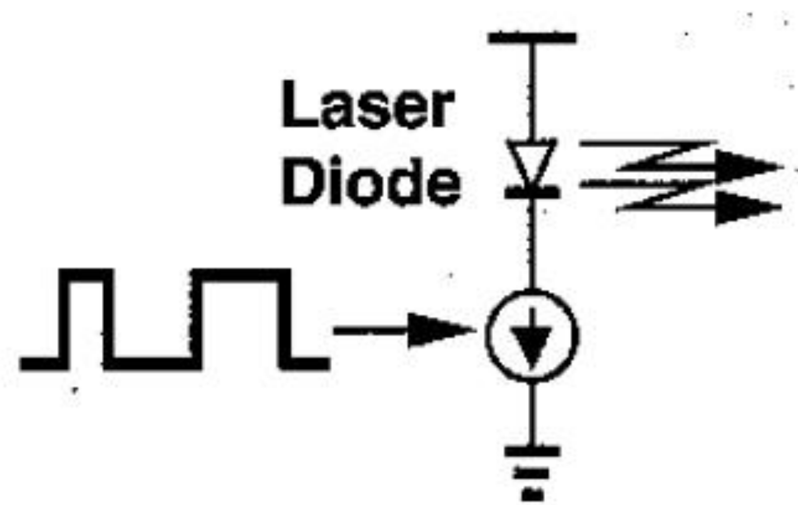
Control putere optica



Control temperatura

Dioda LASER

- Ca si in cazul LED, pentru DL intensitatea luminoasa emisa este o functie de curentul prin dioda
  - aproape exclusiv, DL sunt controlate in curent
  - controlul in curent are avantajul unei viteze mai mari de lucru

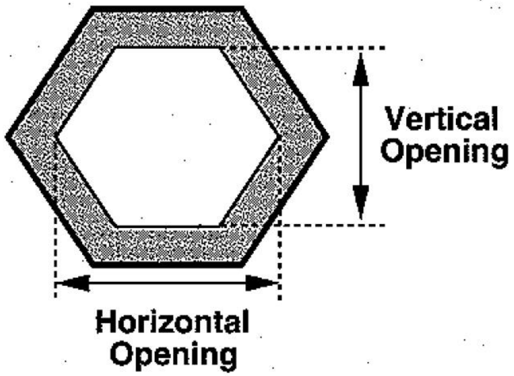


Dioda LASER

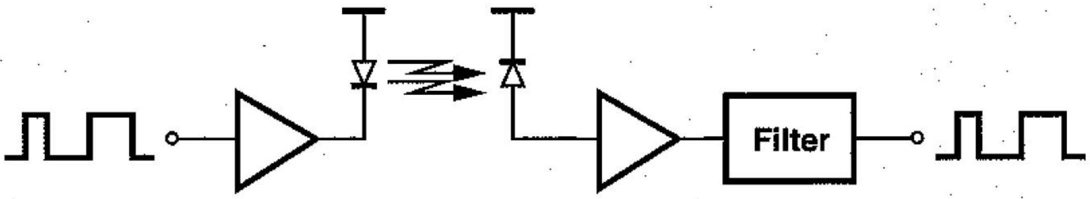
- Cerinte pentru driver-ele de diode laser
  - viteza mare de basculare pentru minimizarea interferentei intersimbol
  - curent mare de iesire
  - capacitatea de a rezista la variatiile de tensiune pe dioda Laser
- Cerintele sunt dificil de respectat deoarece sunt contradictorii
  - viteza mare presupune micsorarea dimensiunii componentelor
  - micsorarea 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”



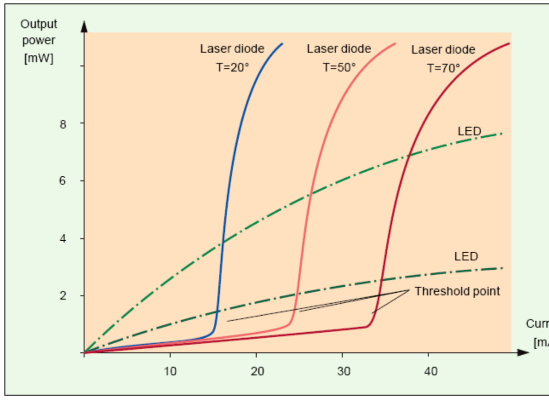
(a)



(b)

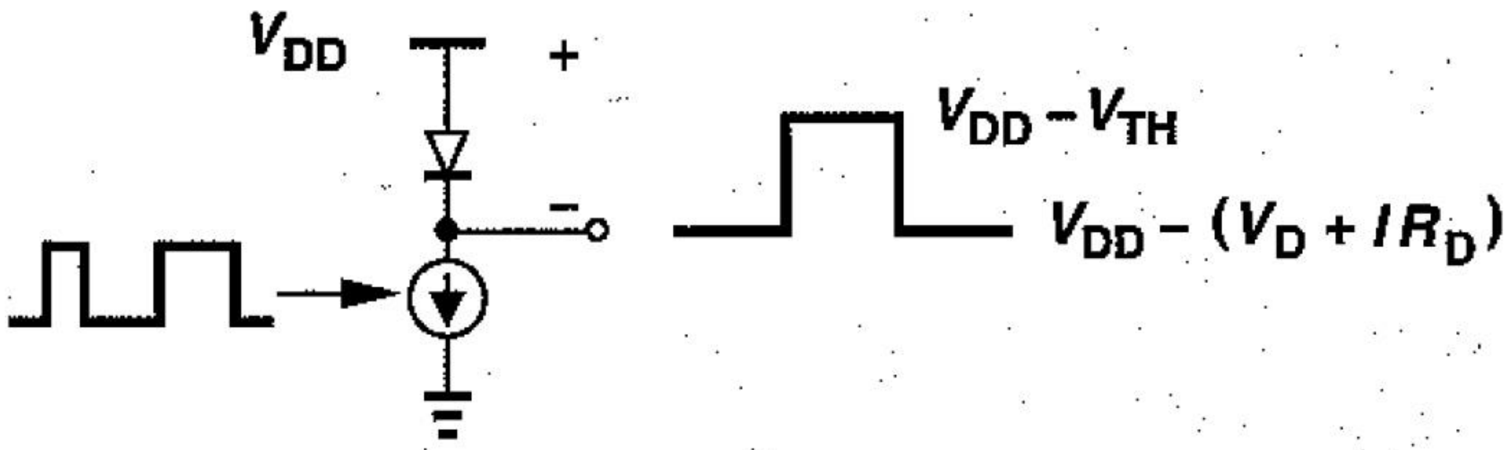
Caracteristici driver-e DL

- 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



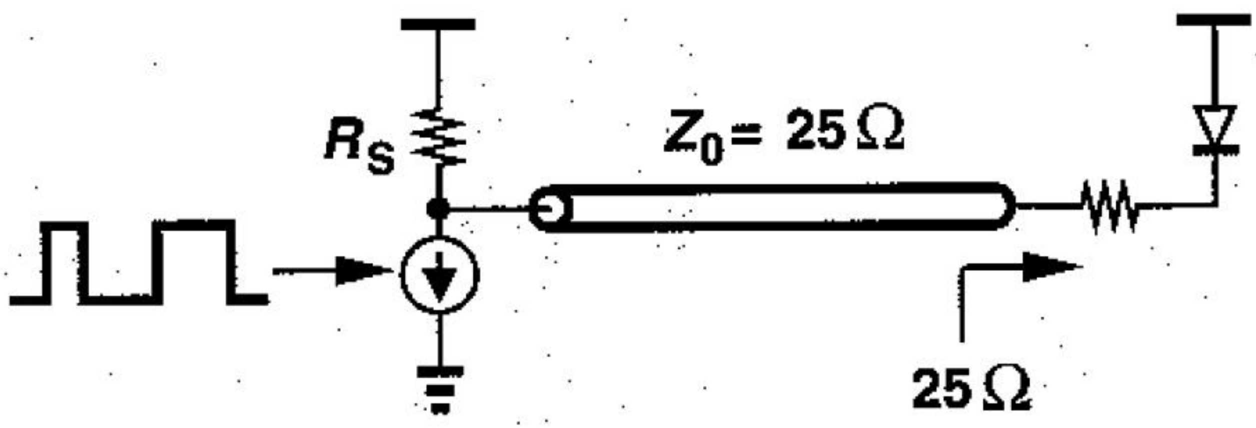
Caracteristici driver-e DL

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



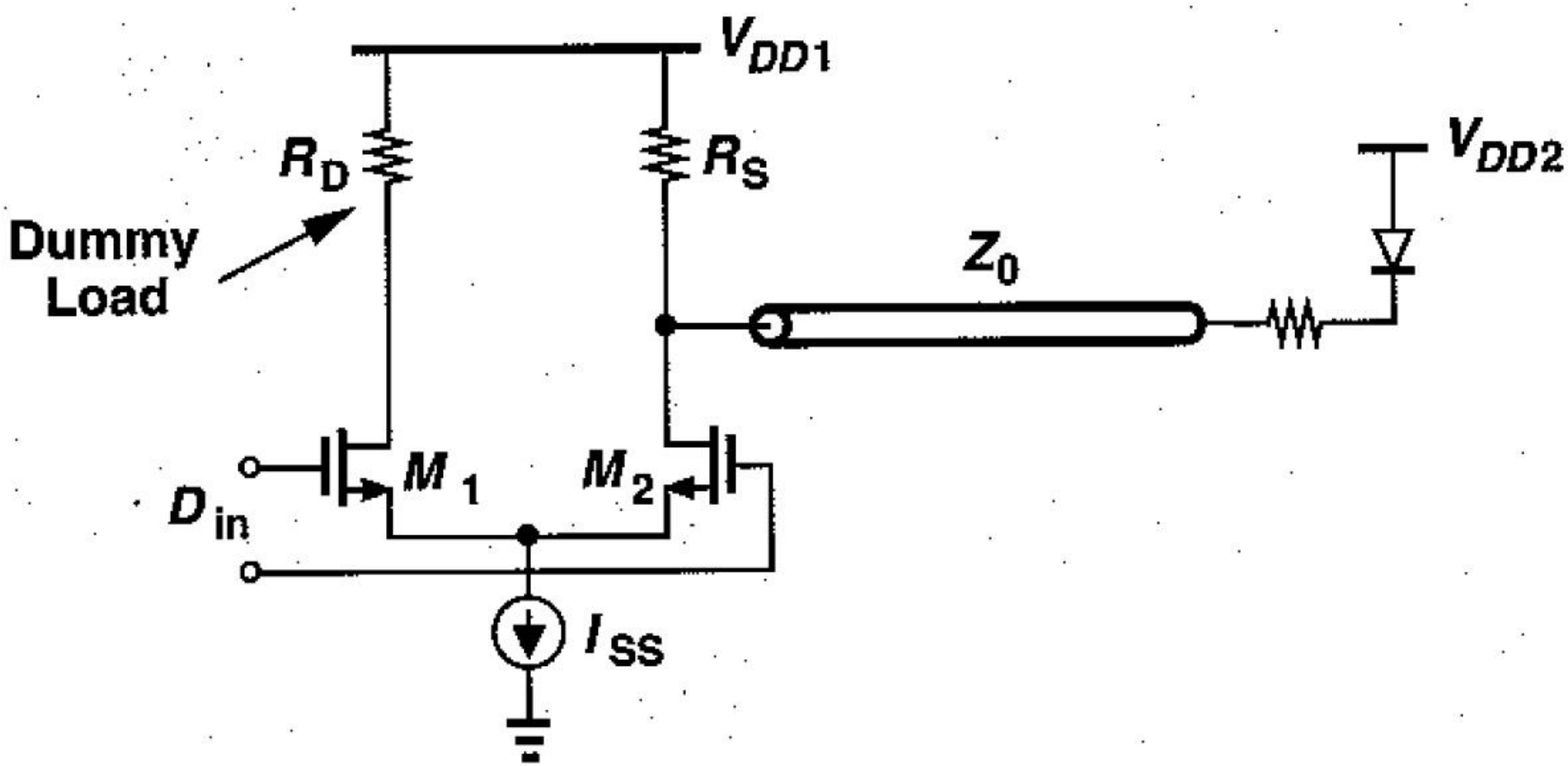
Caracteristici driver-e DL

- Impedante de intrare si iesire
- Se lucreaza la viteze mari (1Gb/s, 10Gb/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 (~25Ω) prin introducerea unui rezistor in serie



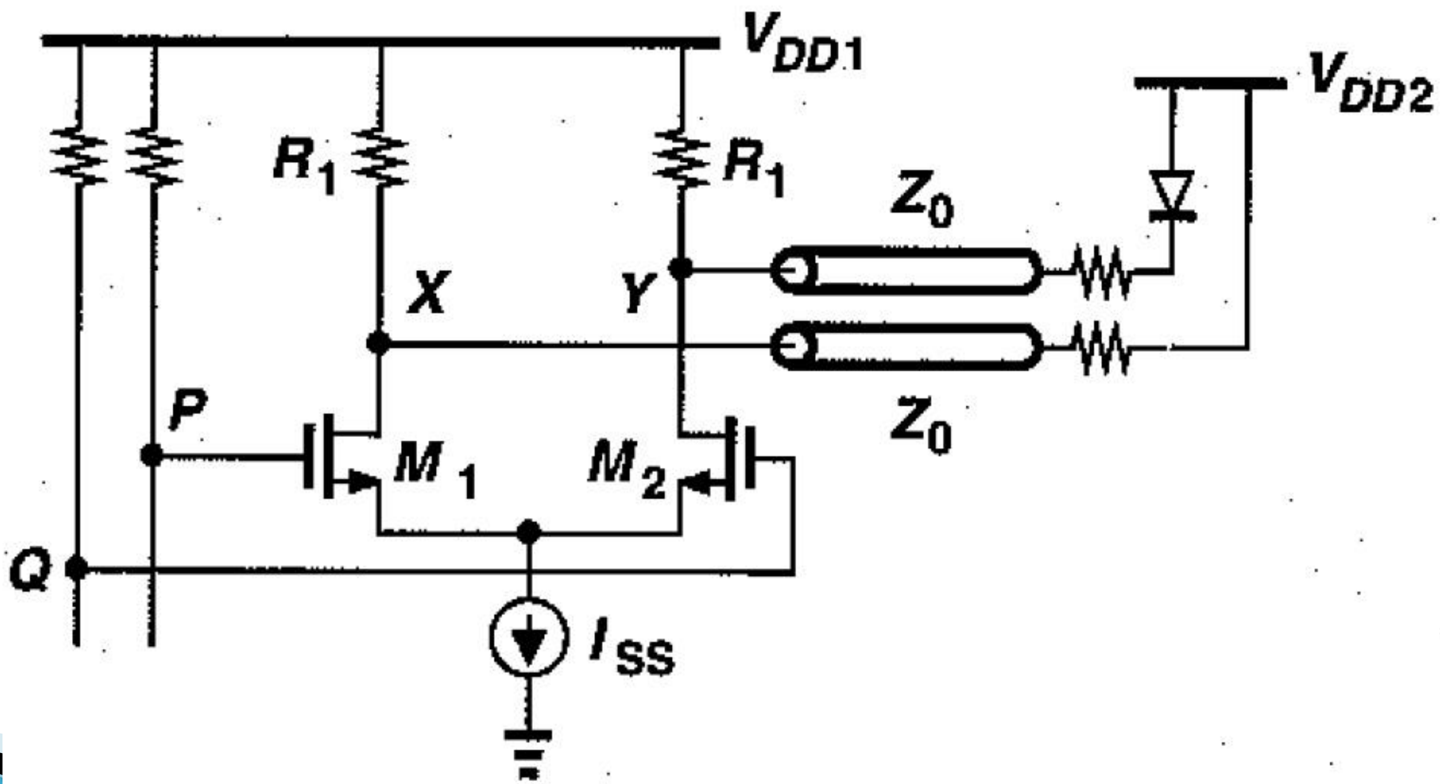
Principii de proiectare

- Tipic etajul de iesire se realizeaza diferential



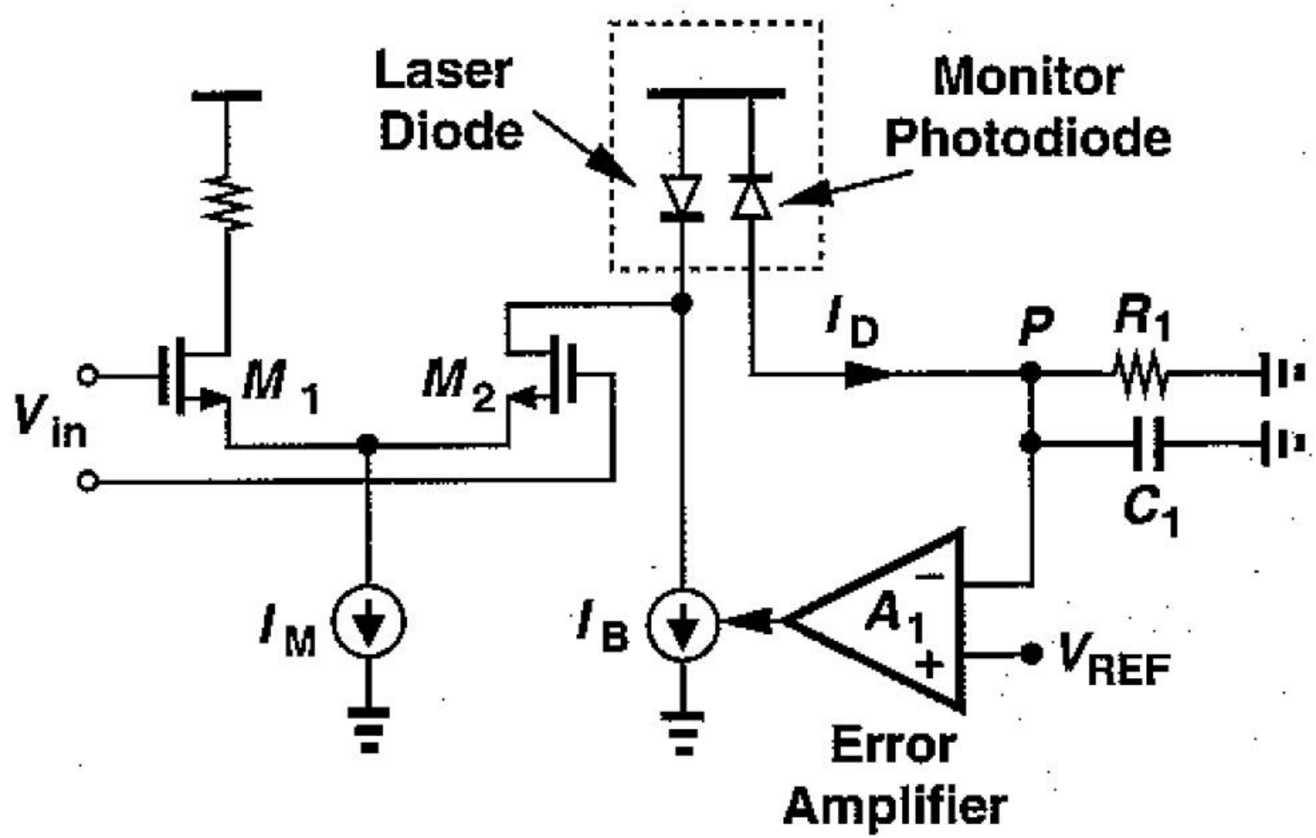
Principii de proiectare

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



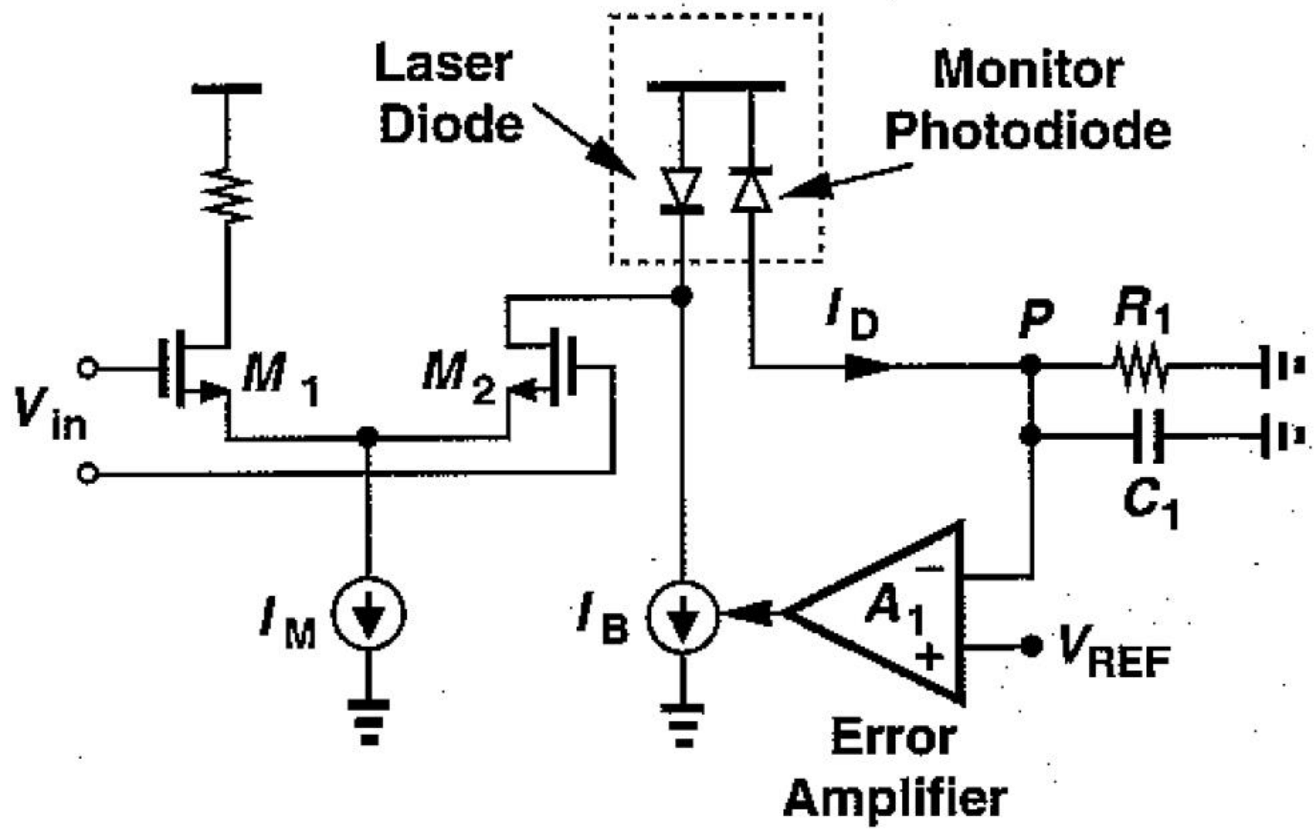
Controlul puterii in DL

- Necesar datorita variatiei curentului de “polarizare”



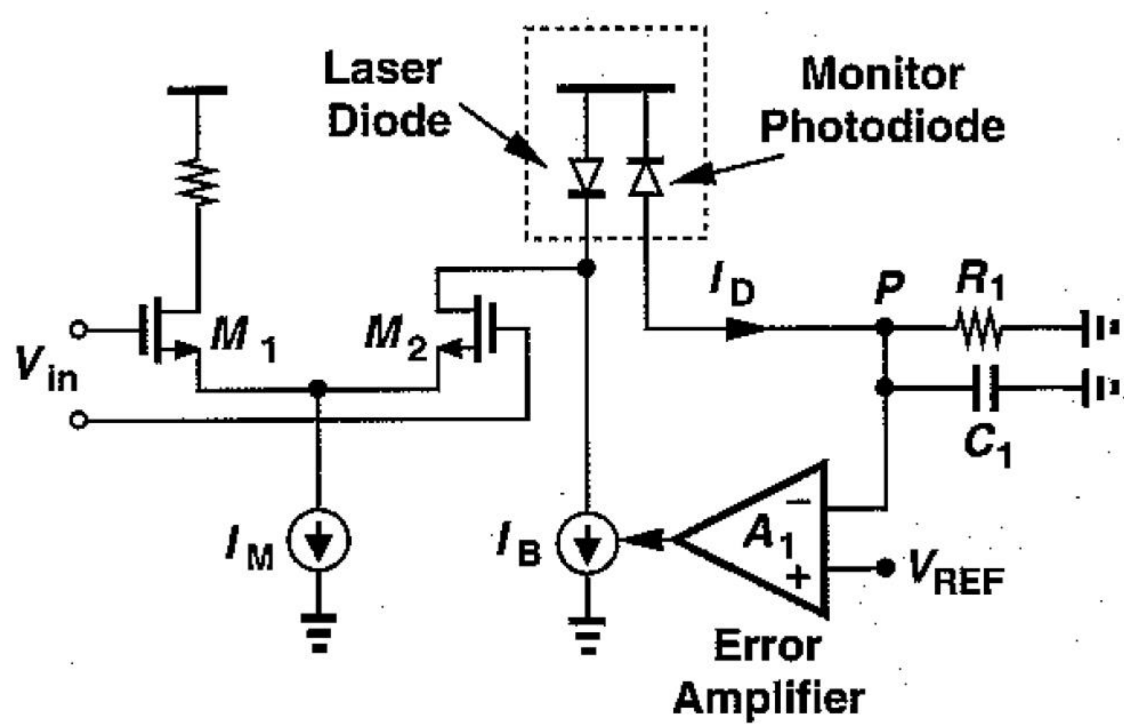
Controlul puterii in DL

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



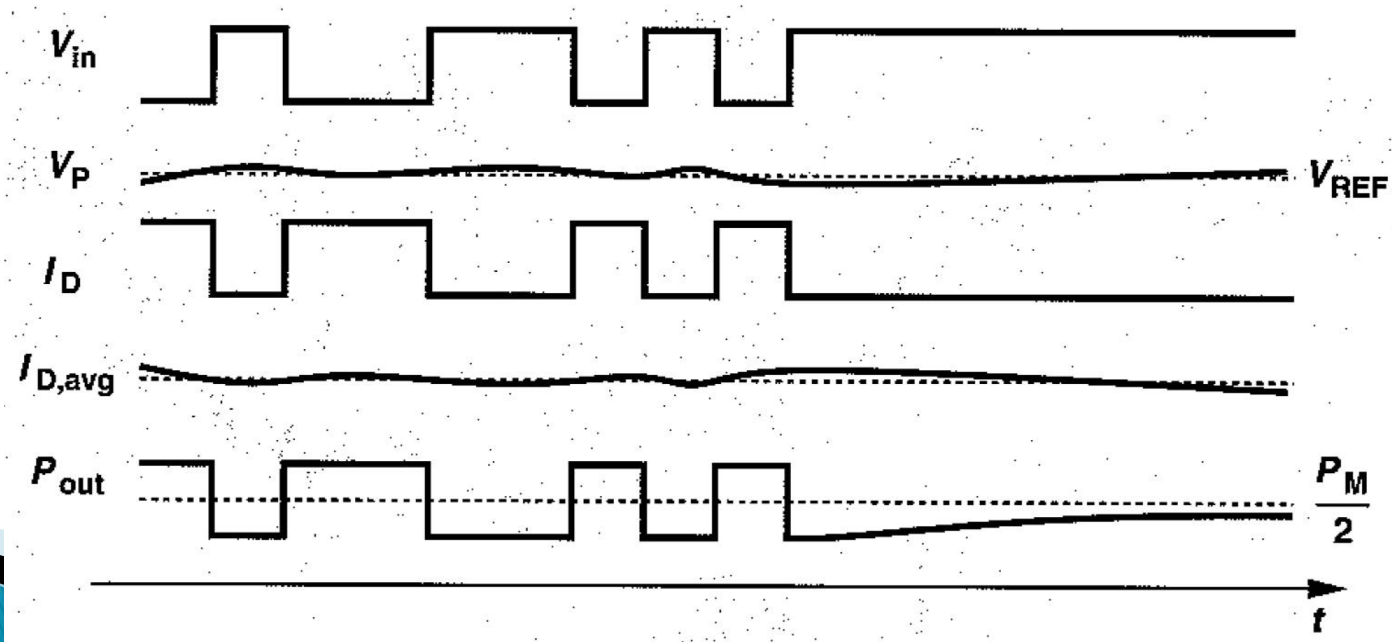
Controlul puterii in DL

- 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 jumatate 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

Cuprins

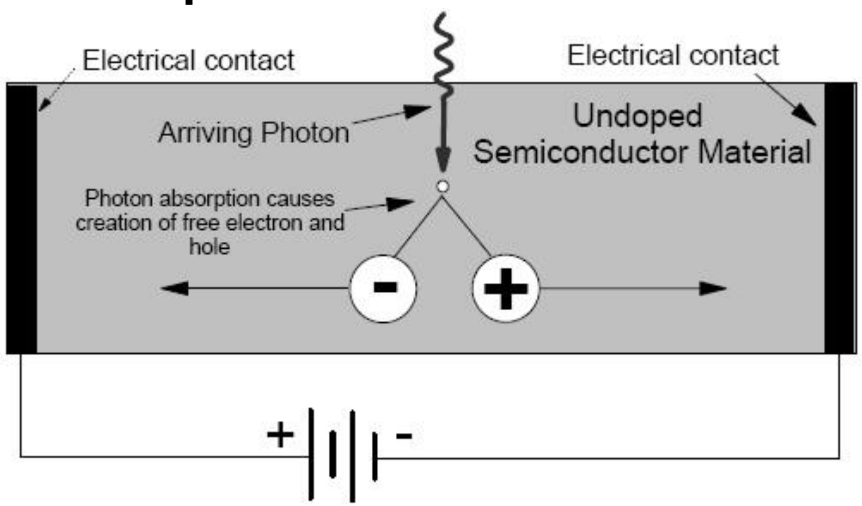
- **Lumina ca undă electromagnetică** (ecuaţiile lui Maxwell, ecuaţia undelor, parametrii de propagare)
- **Elemente de fotometrie şi radiometrie** (mărimi energetice/luminoase)
- **Fibra optică** (realizare, principiu de funcţionare, atenuare, dispersie, banda de frecvenţă)
- **Cabluri optice** (tehnologie, conectori, lipire - splice)
- **Proiectare sistemică a legăturii pe fibra optică** (bandă de frecvenţă, balanţa puterilor)
- **Emiţătoare optice** (LED şi dioda laser - realizare fizică şi functionare)
- **Receptoare optice** (dioda PIN, dioda cu avalanşă - realizare fizică şi functionare)
- **Amplificatoare transimpedanţă** (parametri, scheme tipice, TIA în buclă deschisă, cu reacţie, diferenţiale, control automat al câştigului)
- **Realizarea circuitelor pentru controlul emiţătoarelor optice (**parametri, scheme tipice, controlul puterii, multiplexoare**)**
- **Dispozitive de captare a energiei solare** (principiu de functionare, utilizare, proiectare)

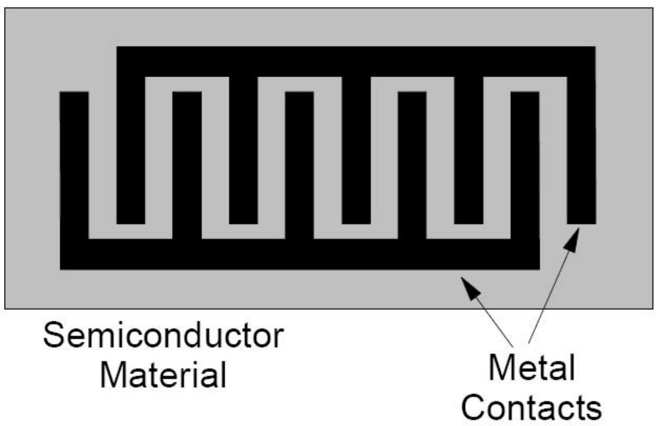
Detectori optici

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

Fotoconductori

- Principiu

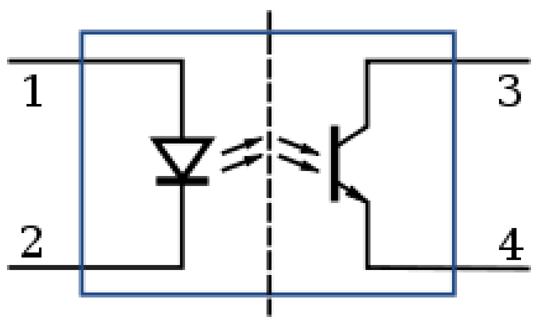


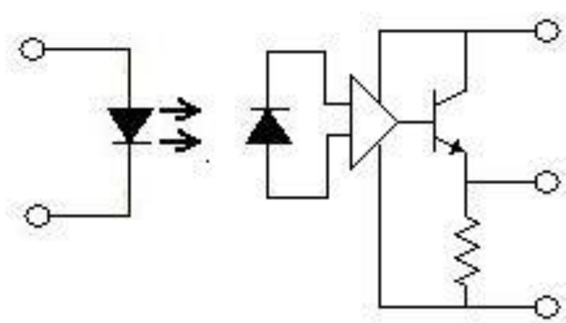


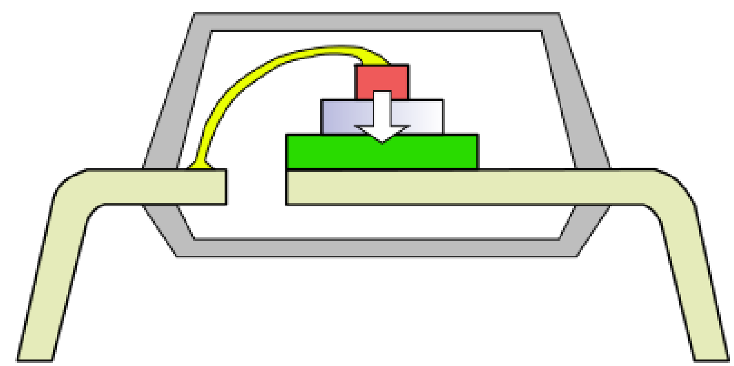
- Dispozitive Metal Semiconductor Metal (filtru interdigital) sunt utilizate pentru usurinta de fabricare si integrare in aplicatii mai putin pretentioase

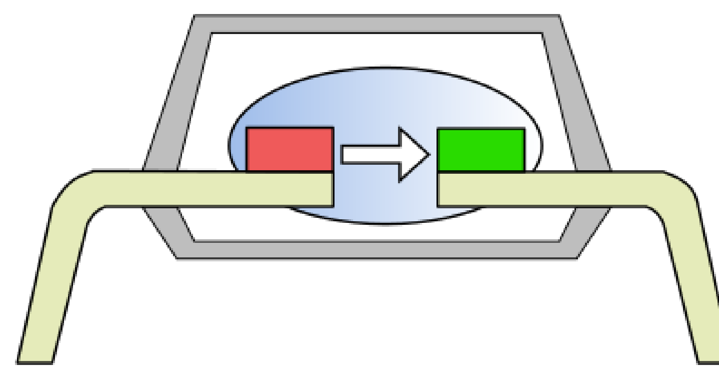
Optocuploare

- utilizate pentru a oferi izolare electrica intre doua sectiuni ale unui circuit
  - izolarea portiunii de comanda si/sau masura de partea de “forta” a circuitului



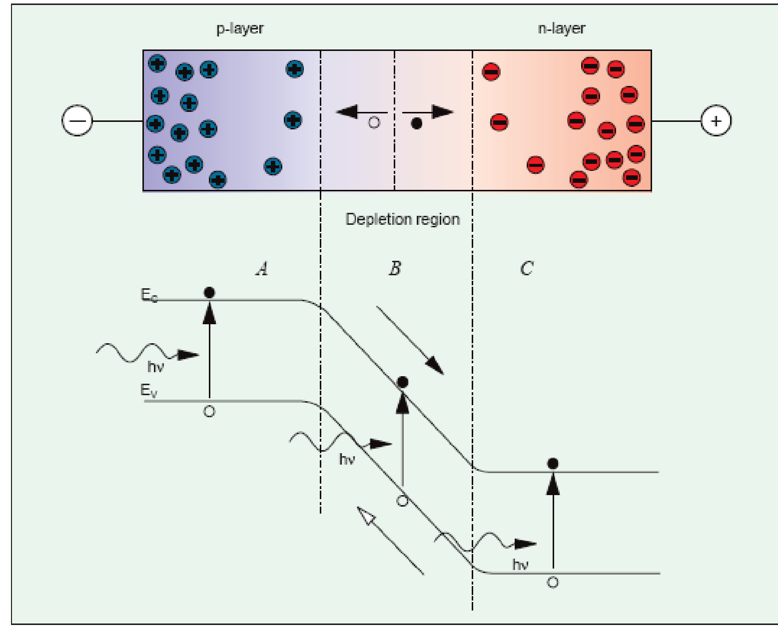


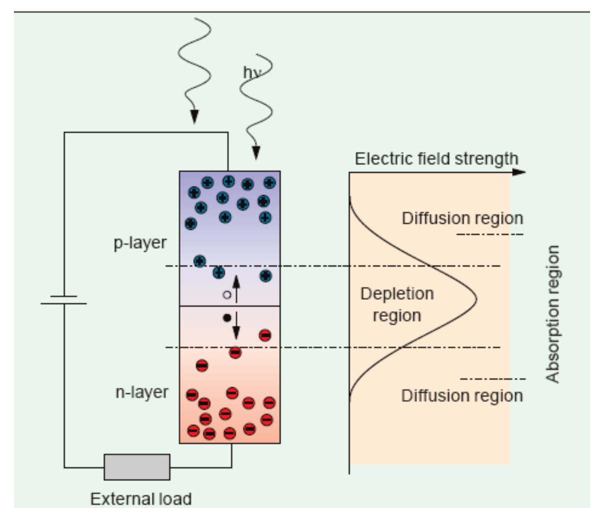




Fotodioda – Principiul de operare

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





Fotodioda – Principiul de operare

- Energia necesara pentru eliberarea unei perechi electron gol

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

- Lungime de unda de taiere

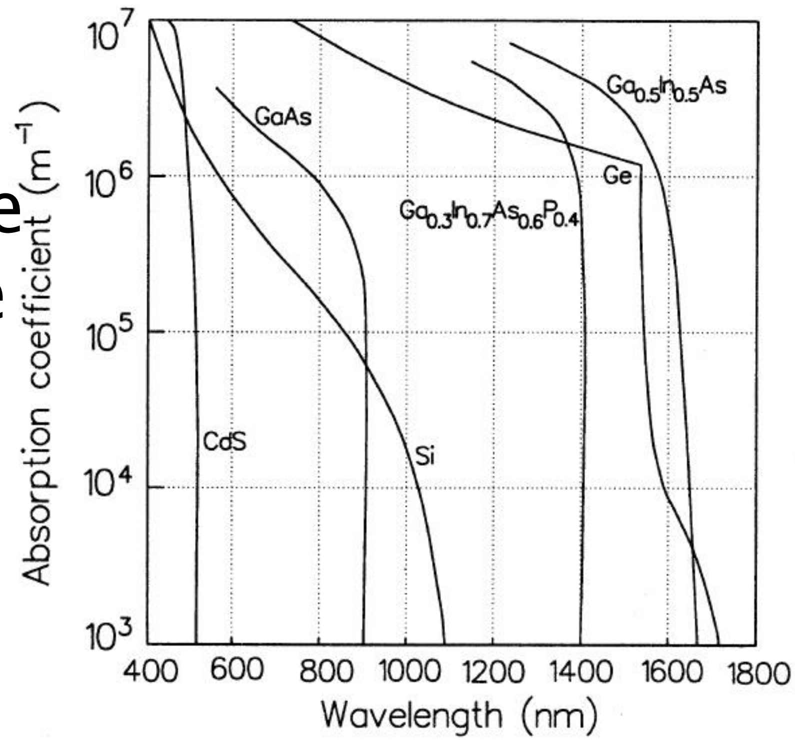
$$\lambda_{\max} = \frac{hc}{E_g}$$

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

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

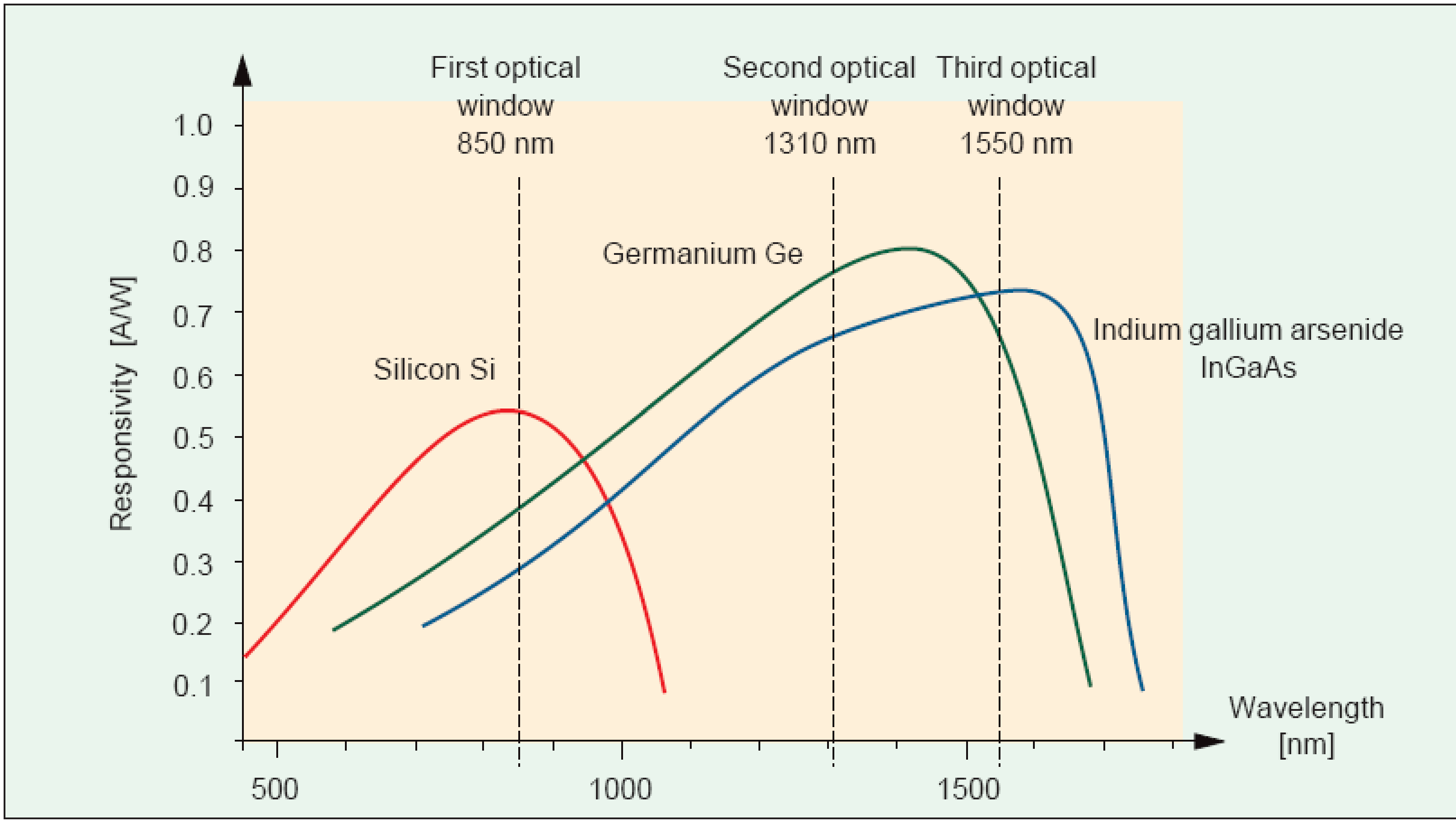
Fotodioda – Principiul de operare

- Coeficientul de absorbtie pentru materialele uzuale



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

Materiale utilizate pentru fotodiode



Fotodioda - Marimi caracteristice

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

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

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

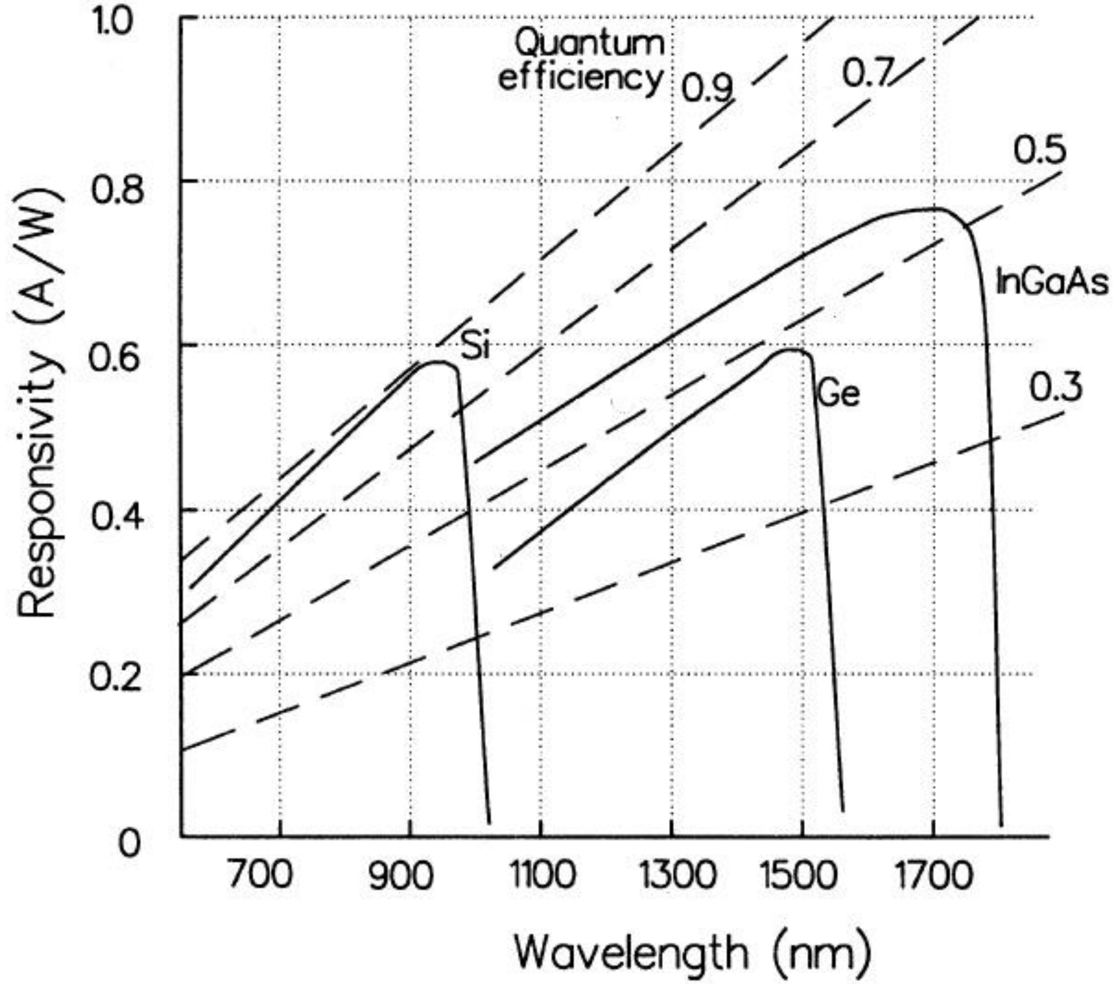
$$\eta = \frac{I/e}{P/h\nu}$$

- Responzivitatea

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

Fotodiode – marimi caracteristice

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



Materiale utilizate pentru fotodiode

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

- Dezavantajul major pentru Ge este curentul de intuneric mare

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

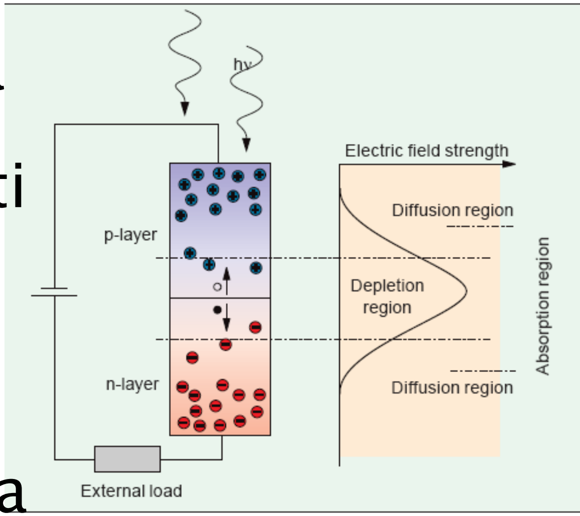
Curent de intuneric

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

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

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

Fotodioda PIN

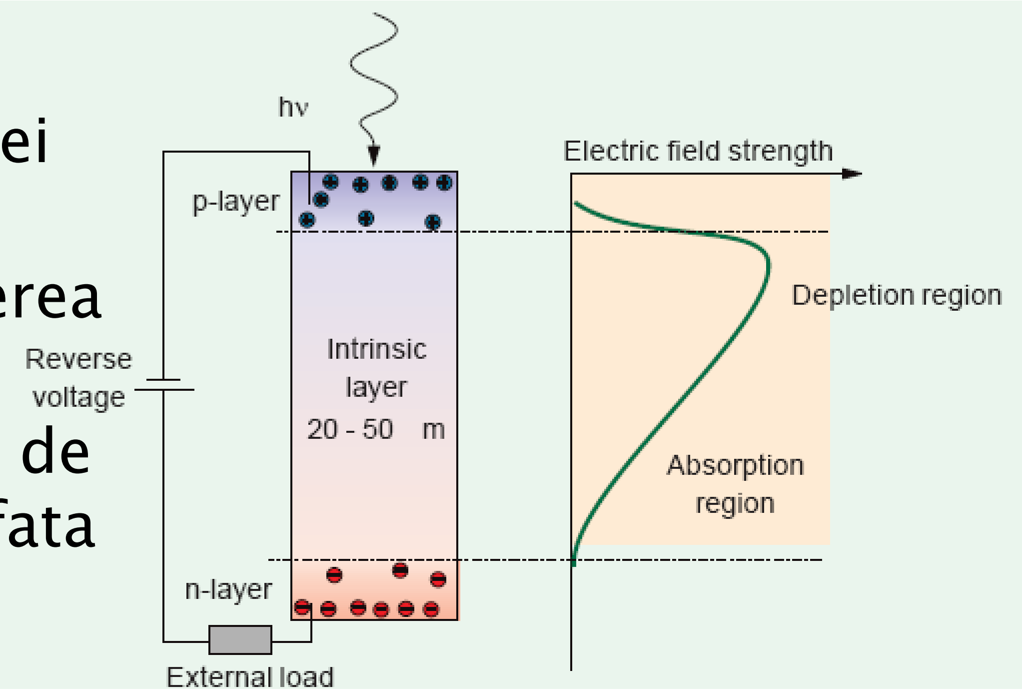


- Existenta campului electric in regiunea golita de purtatori face ca eventualii purtatori generati optic sa fie accelerati spre terminale pentru constituirea fotocurentului
- Problemele utilizarii diodei pn polarizate invers ca fotodetector sunt generate de adancimea extrem de mica a zonei golite (w)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

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

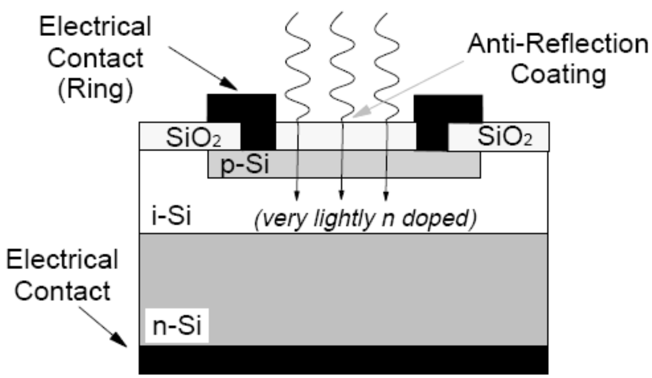
Fotodioda PIN

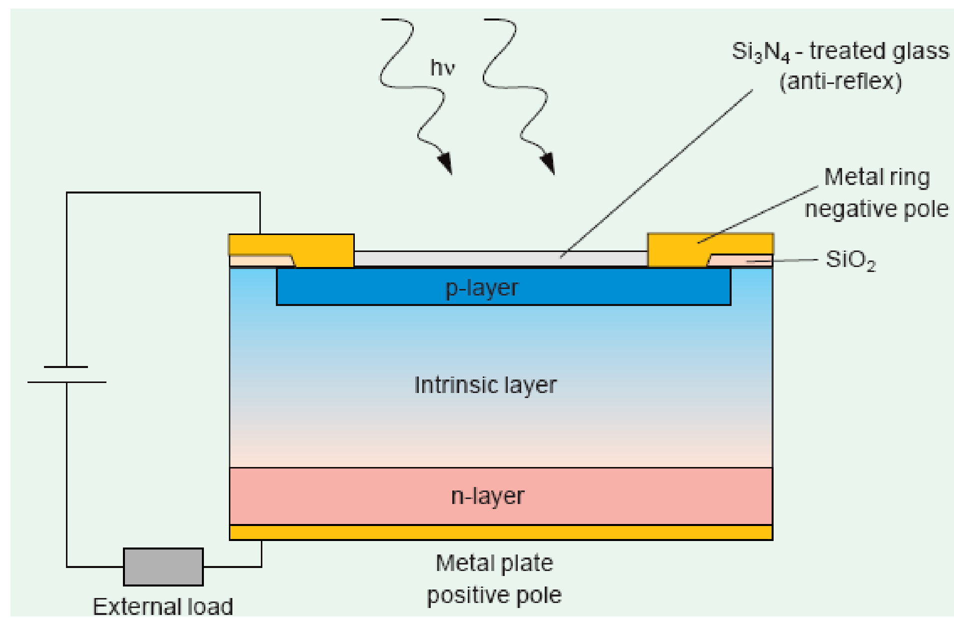
- Solutia consta in introducerea unui strat foarte slab dopat (intrinsec) intre cele doua zone ale diodei
  - creste volumul de absorbtie deci creste sensibilitatea fotodiodei
  - capacitatea jonctiunii scade ducand la cresterea vitezei
  - este favorizat curentul de conductie (mai rapid) fata de cel de difuzie



Structura fotodiodei PIN

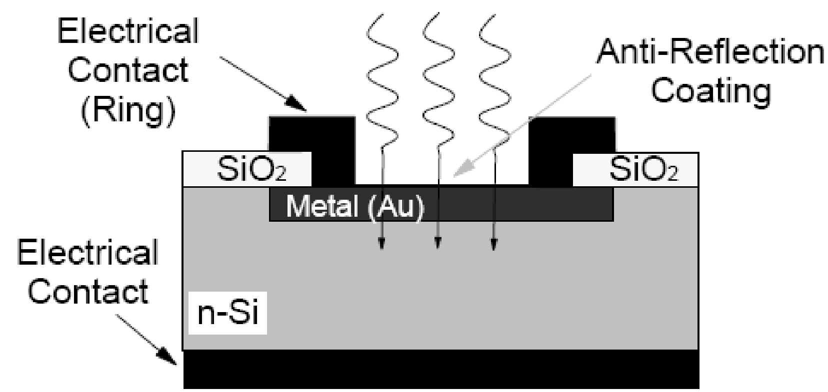
- tipic, adancimea stratului intrinsec este de 20–50μm
- cresterea suplimentara a adancimii ar duce la cresterea timpului de tranzit
  - w=20μm -> $T_{tr} \cong 0.2$ns





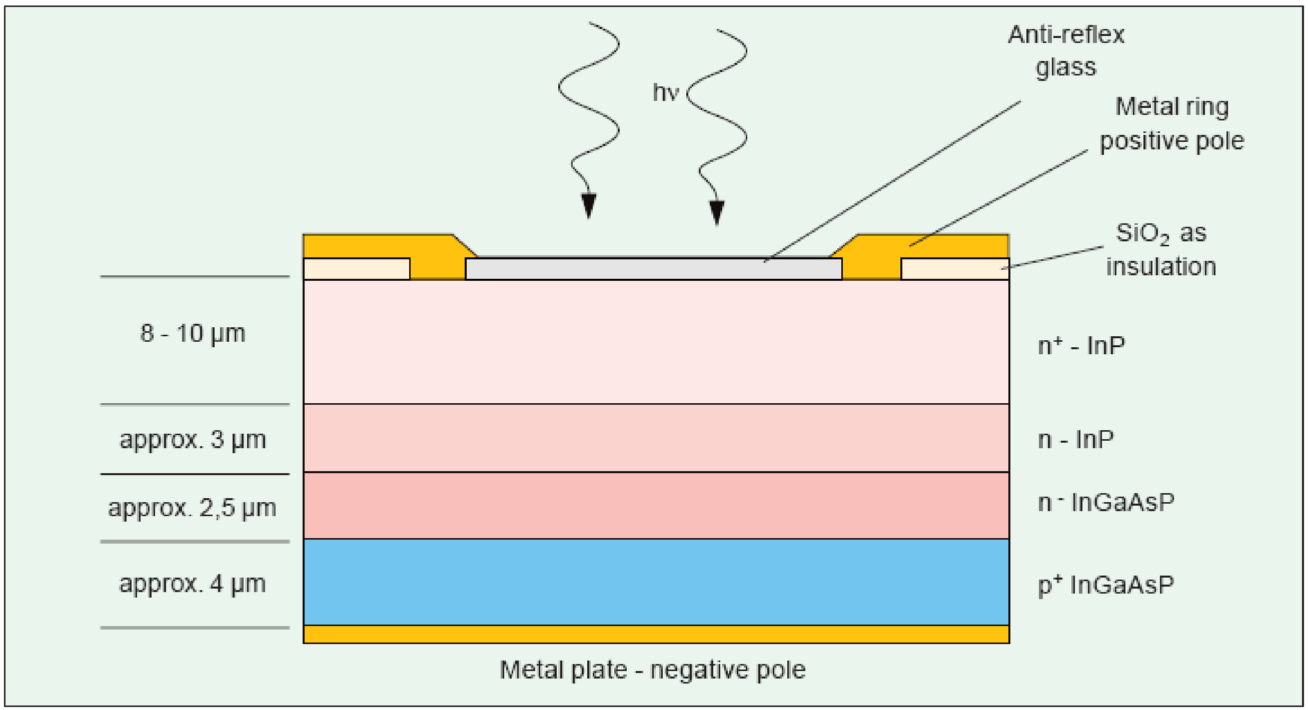
Structura fotodiodelor Schottky

- se bazeaza pe jonctiunea metal semiconductor
- vitezele de lucru sunt mult mai mari, metalul fiind un bun conductor realizeaza evacuarea mult mai rapida a purtatorilor din jonctiune
- permite utilizarea unor materiale cu eficienta mai mare dar care nu pot fi dopate simultan p si n pentru utilizare in PIN
- modulatie cu 100GHz posibila



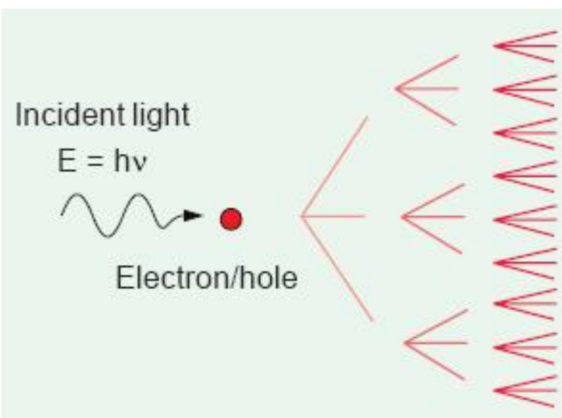
Fotodioda PIN pentru lungimi de unda crescute (1550nm)

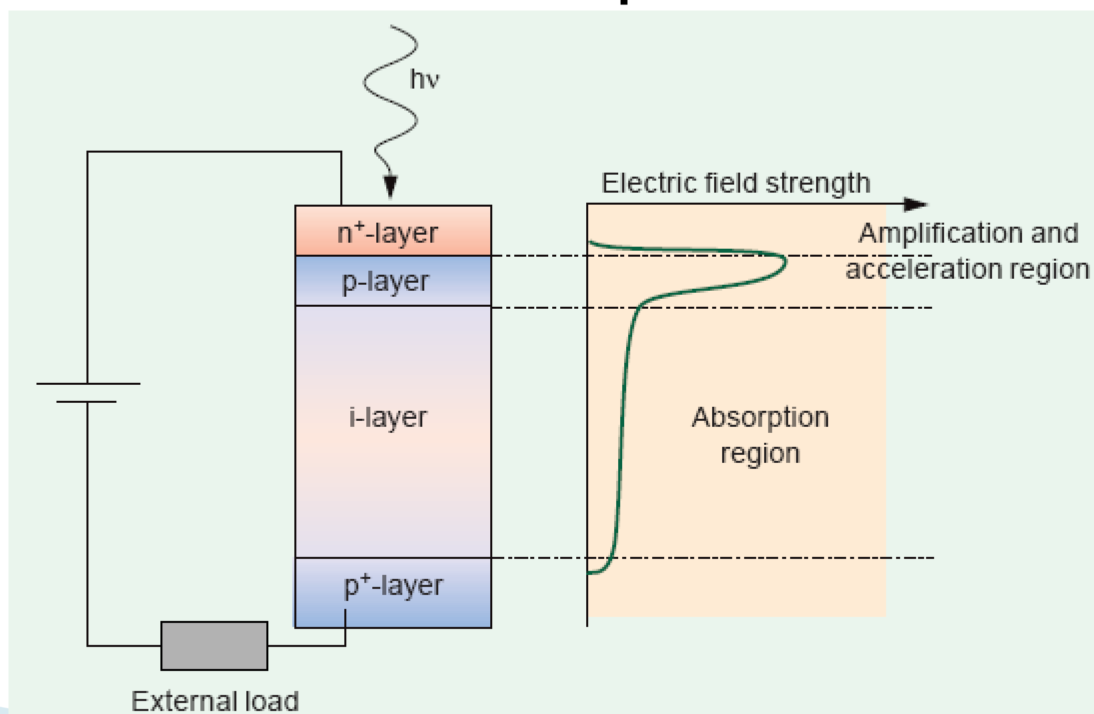
- se utilizeaza tipic
  - InGaAsP pe substrat InP
  - GaAlAsSb pe substrat GaSb



Fotodioda PIN cu multiplicare in avalansa

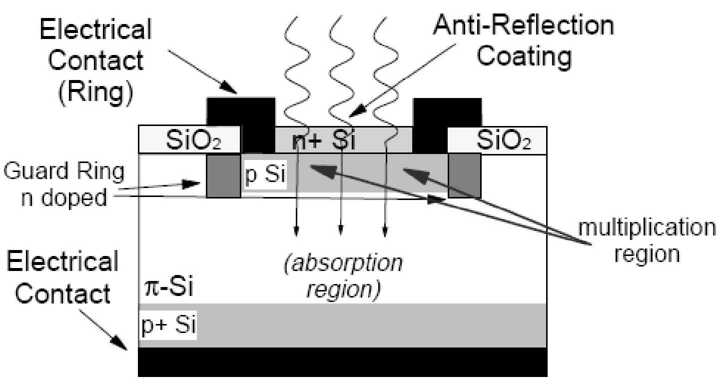
- daca viteza purtatorilor este suficient de mare genereaza noi perechi electron/gol prin ionizare de impact
- amplificarea are loc in acelasi timp cu detectia

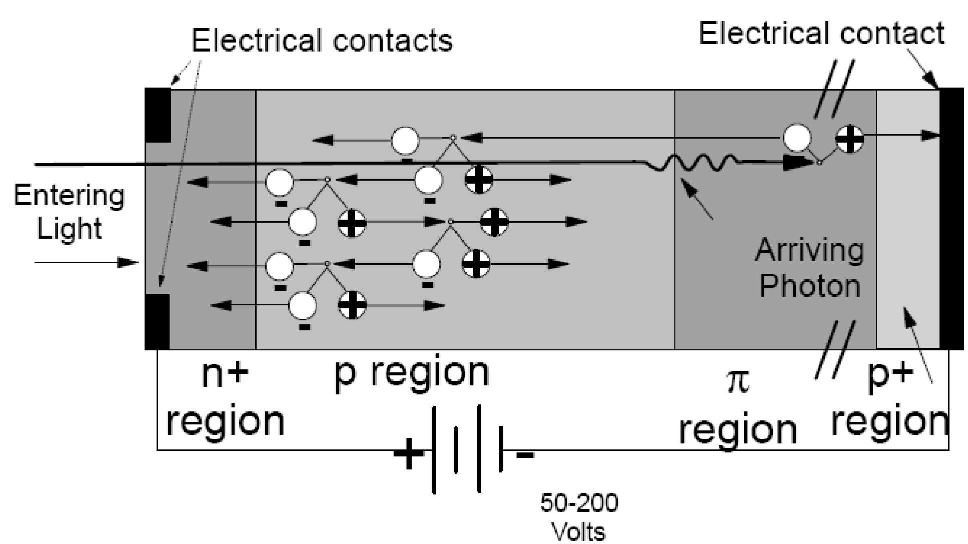




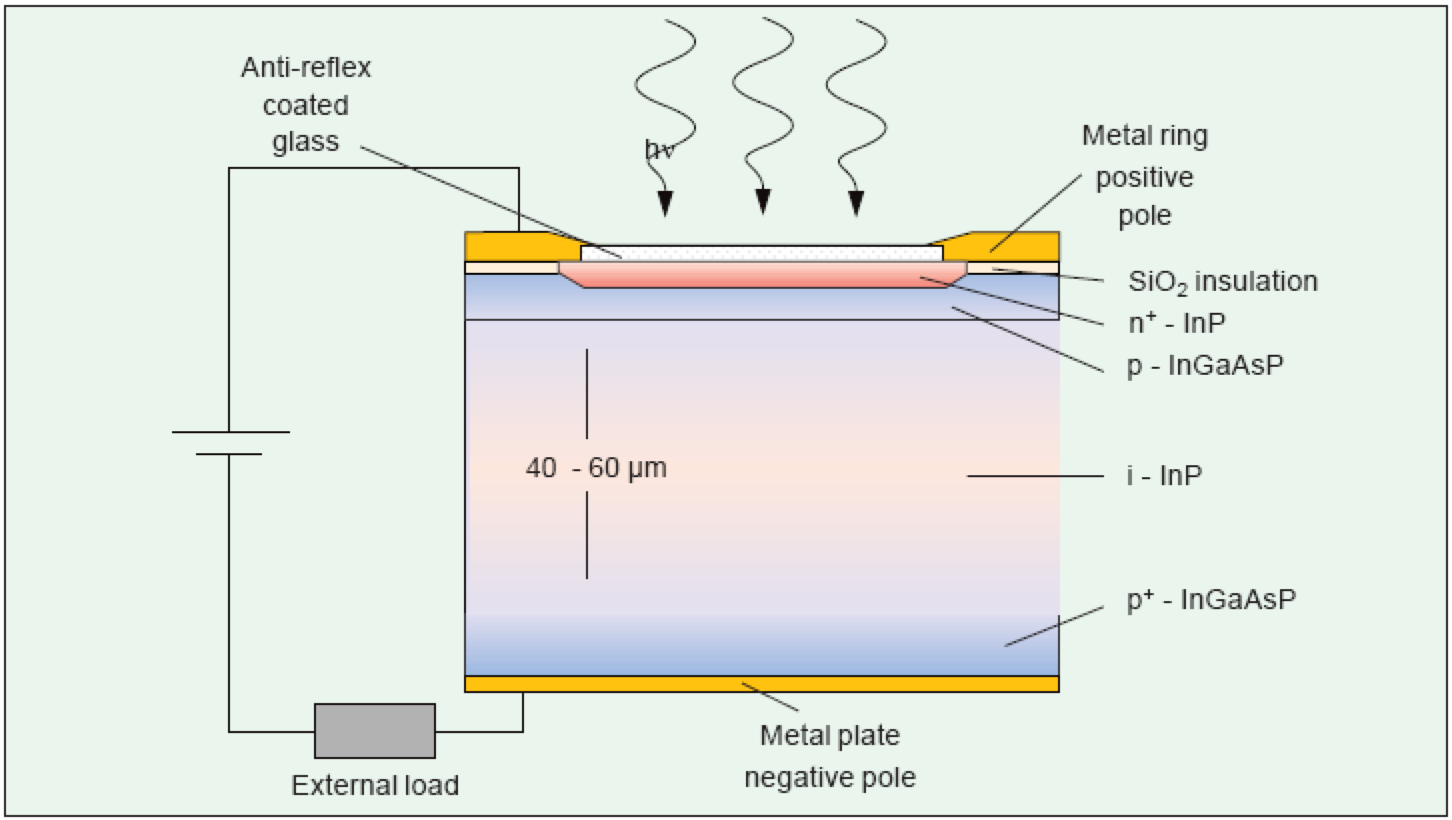
Functionarea fotodiodei cu multiplicare in avalansa

- campuri electrice de ordinul minim: $3x10^5$ V/m, tipic: 10^6 V/m sunt necesare
- aceste campuri sunt generate de tensiuni inverse de polarizare de ordinul 50-300V
- structura este modificata pentru concentrarea campului in zona de accelerare





Structura fotodiodei cu multiplicare in avalansa



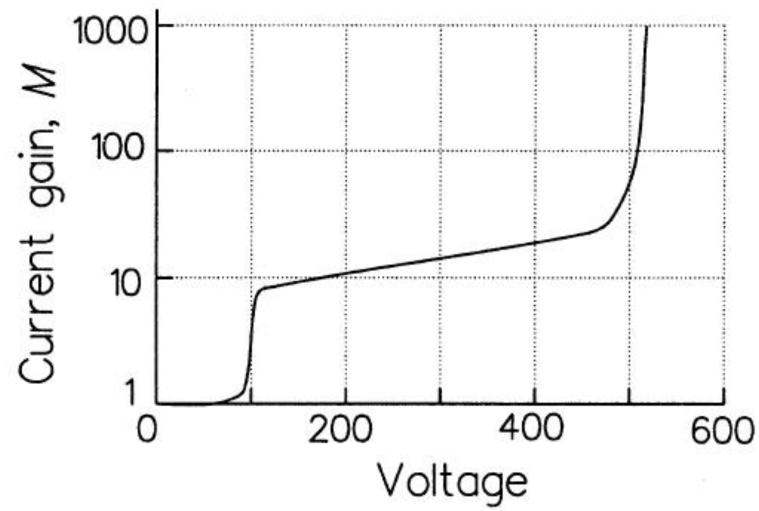
Caracteristicile fotodiodei cu multiplicare in avalansa

- factorul de multiplicare caracterizeaza amplificarea fotocurentului generat

$$M = \frac{I_M}{I}$$

- Responzivitatea

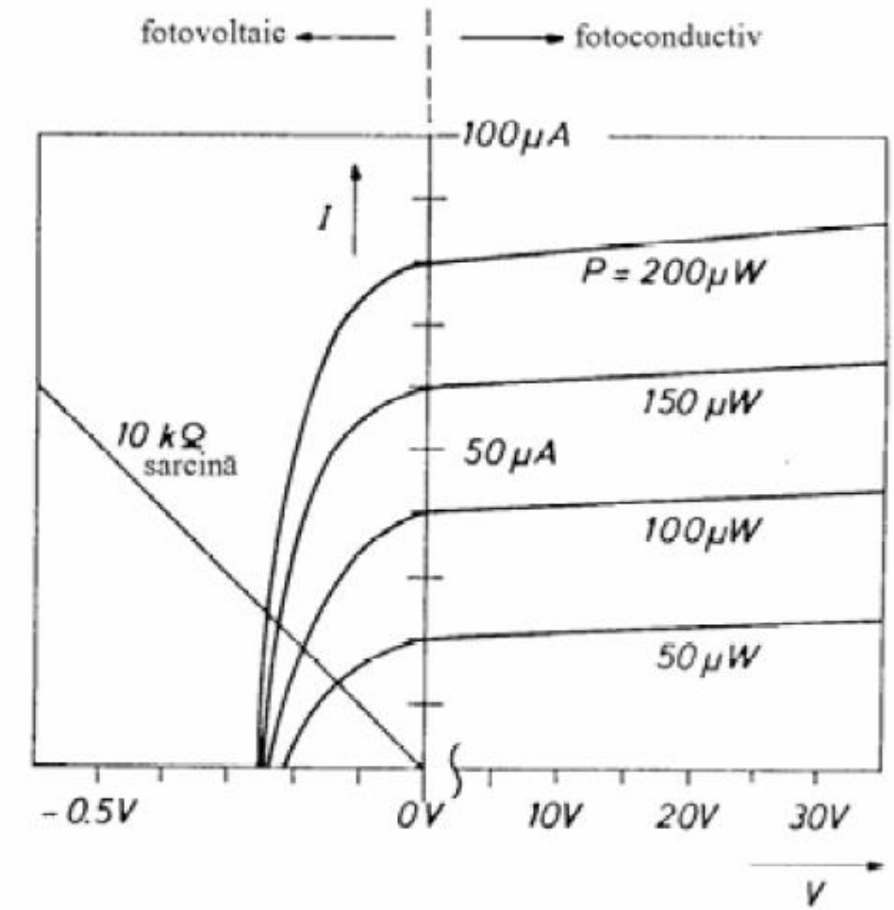
$$R = \frac{I}{P_o} = \frac{\eta \cdot e \cdot \lambda}{hc} \cdot M$$



Dezavantaje

- tensiuni inverse de polarizare mari cresc complexitatea circuitului
- diodele cu multiplicare in avalansa sunt intrinsec mai zgomotoase (curentul de zgomot este amplificat de asemenea)
- factorul de multiplicitate are o componenta aleatorie (zgomot suplimentar)
- viteza mai redusa (timp de generare al avalansei)

Caracteristici curent/tensiune Fotodioda

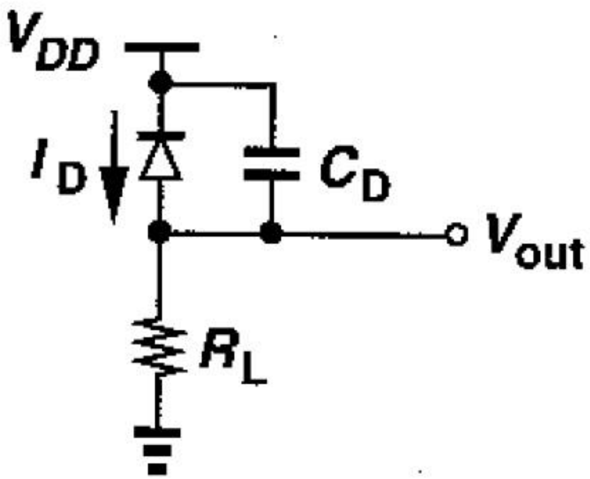


Amplificatoare transimpedanta

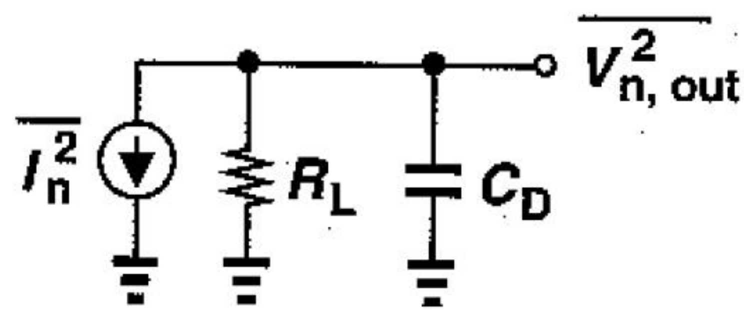
- Fotodiodele genereaza un curent proportional cu puterea optica receptionata
- Primul pas necesar este conversia acestui curent la o tensiune
- Amplificatoarele transimpedanta sunt amplificatoarele atacate in curent si care ofera la iesire o tensiune proportionala cu acesta
- Amplificarea este masurata in Ω (kΩ)

Amplificatoare transimpedanta

- Cel mai simplu amplificator transimpedanta este un rezistor



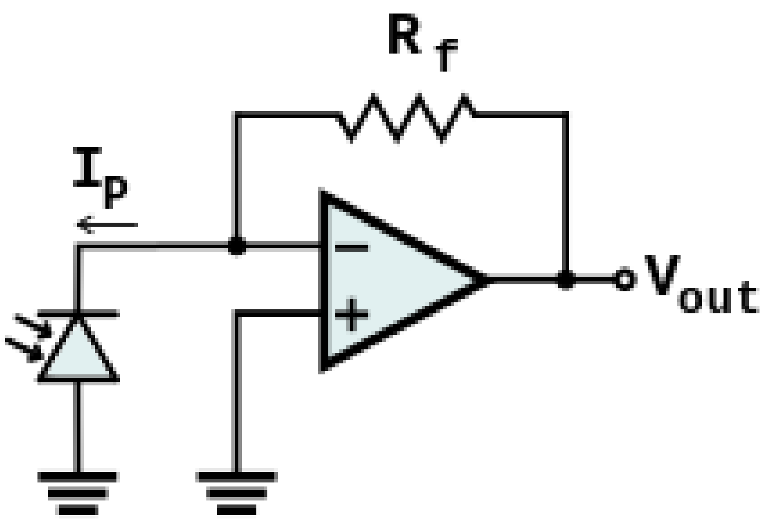
(a)



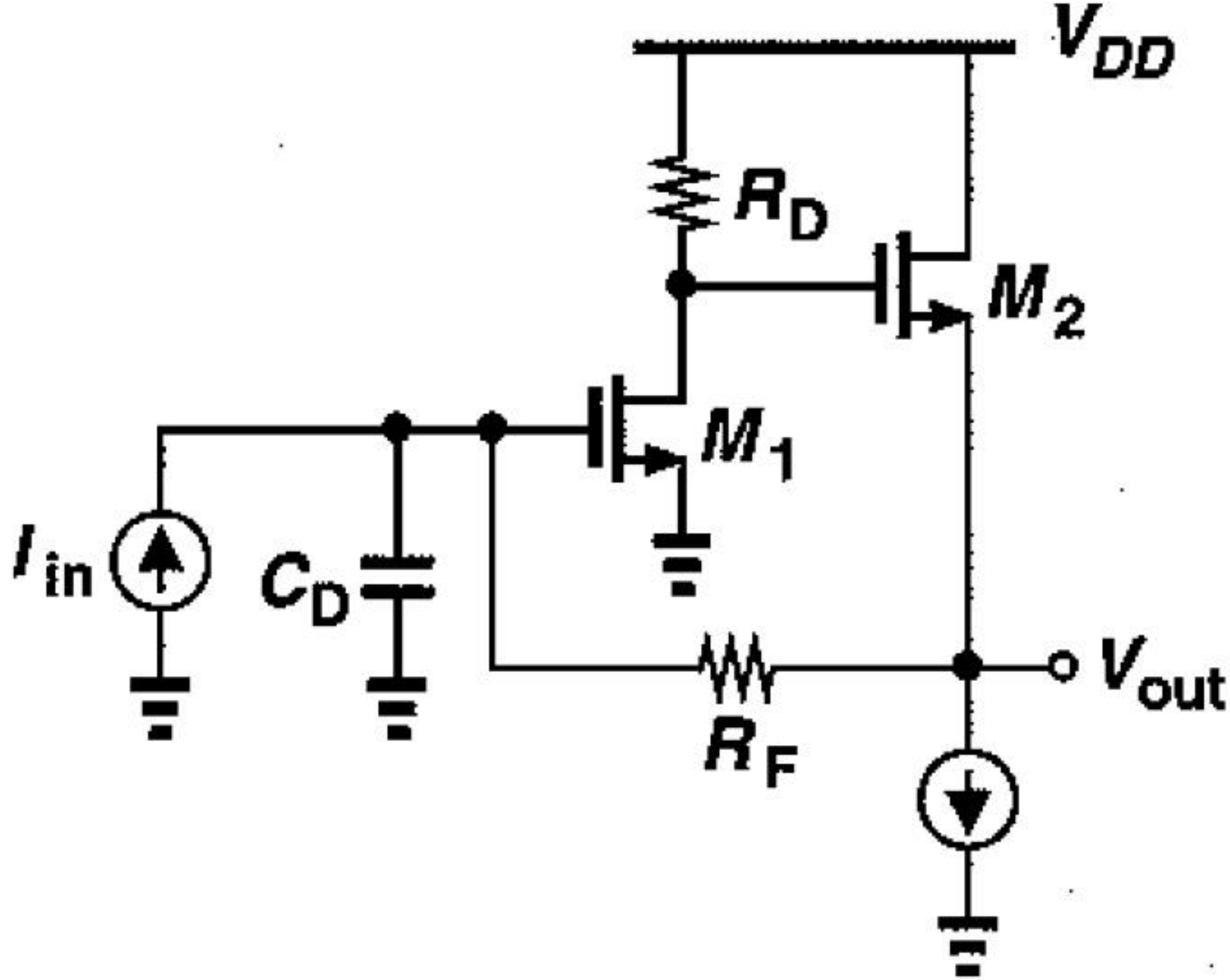
(b)

Amplificatoare transimpedanta

- Trebuie realizat un compromis intre
  - zgomot
  - castig
  - viteza
- De obicei sunt realizate cu reactie



Amplificatoare transimpedanta



Zgomotul traductorilor electro-optici

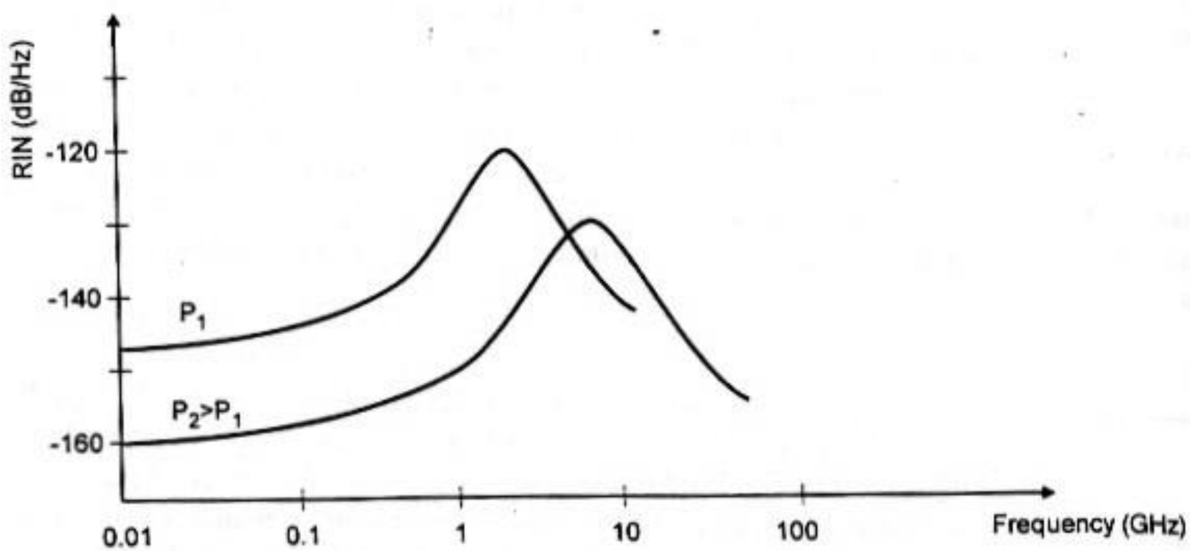
Zgomotul emitatorilor optici

- LED
  - este considerat o sursa lipsita de zgomot
  - nu contamineaza semnalul cu zgomot suplimentar
- Dioda LASER
  - fluctuatii de faza, determina o largire a spectrului emis
  - fluctuatii de intensitate, determina zgomotul de intensitate introdus de dioda
  - RIN – Relative Intensity Noise

$$RIN[1/Hz] = \frac{\langle P_n^2 \rangle}{\langle P^2 \rangle \cdot BW}$$

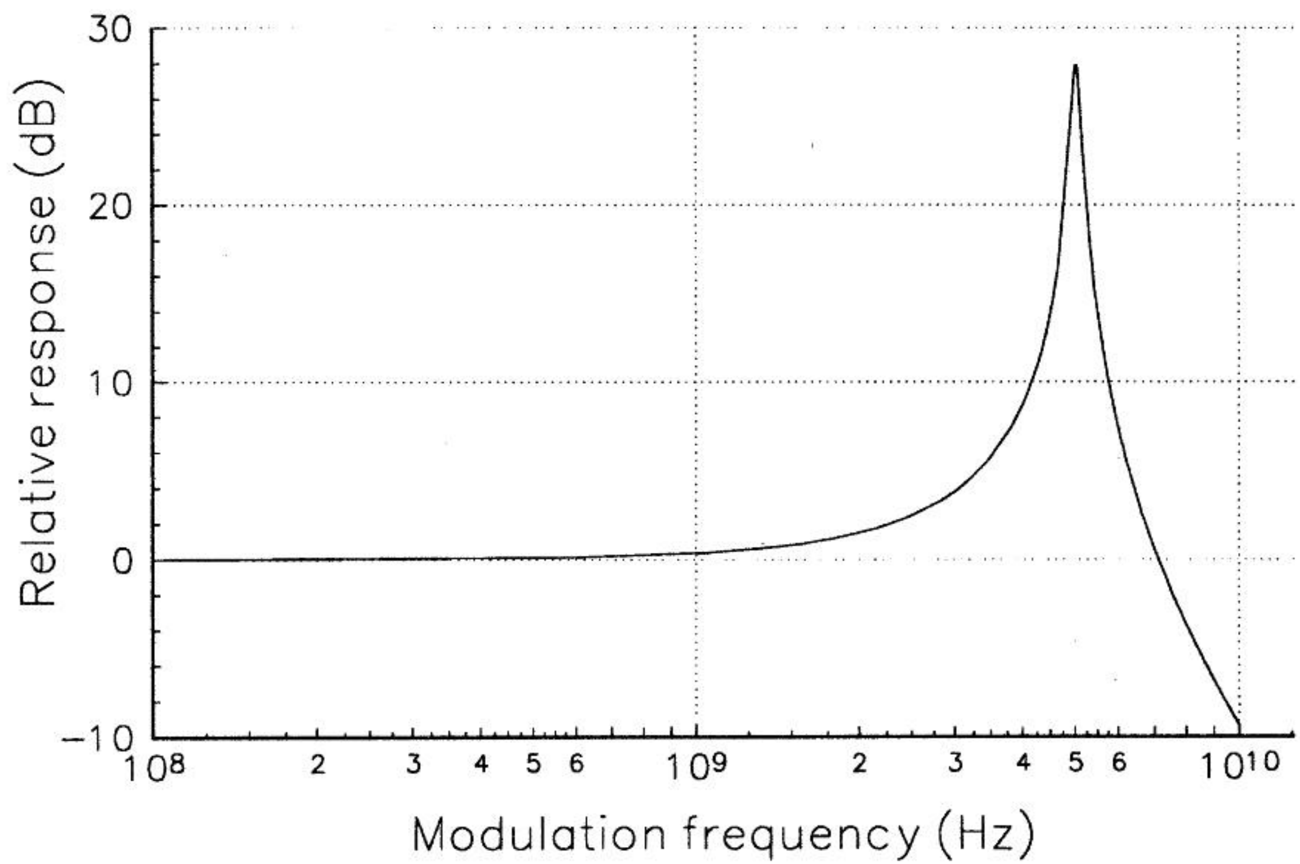
RIN

- reprezinta o densitate spectrala de zgomot
  - puterea de zgomot depinde de RIN si de banda semnalului
- Depinde de puterea semnalului
  - P^{-3} la puteri mici, P^{-1} la puteri mari



Raspunsul unei diode laser

- oscilatii de relaxare – x GHz



EIN

- Equivalent Input Noise
  - Ri – rezistenta de intrare in circuitul de modulatie a diodei
  - Variatiile de putere (zgomot) echivalente unor variatii de curent (zgomot) prin dioda

$$\left\langle P_n^2 \right\rangle = r \cdot \left\langle I_n^2 \right\rangle$$

$$EIN[W] = R_i \cdot \left\langle I_n^2 \right\rangle$$

1 Hz banda

$$EIN[W / Hz] = RIN \cdot \left(I_0 - I_{th}\right)^2 \cdot R_i$$

Zgomotul fotodiodei

- NEP
  - Noise Equivalent Power
  - r – responzivitatea diodei

$$NEP[W] = \frac{\int \sqrt{\left\langle i_n^2 \right\rangle} df}{r}$$

  - r depinde de λ, implica NEP depinde de λ
  - In cataloage apare de obicei densitatea spectrala

$$NEP[W/\sqrt{Hz}] = \frac{\sqrt{\left\langle i_n^2 \right\rangle}}{r} = \frac{NEP}{\sqrt{BW_{PD}}}$$

Zgomotul fotodiodei

- NEP
  - cea mai mica putere detectabila

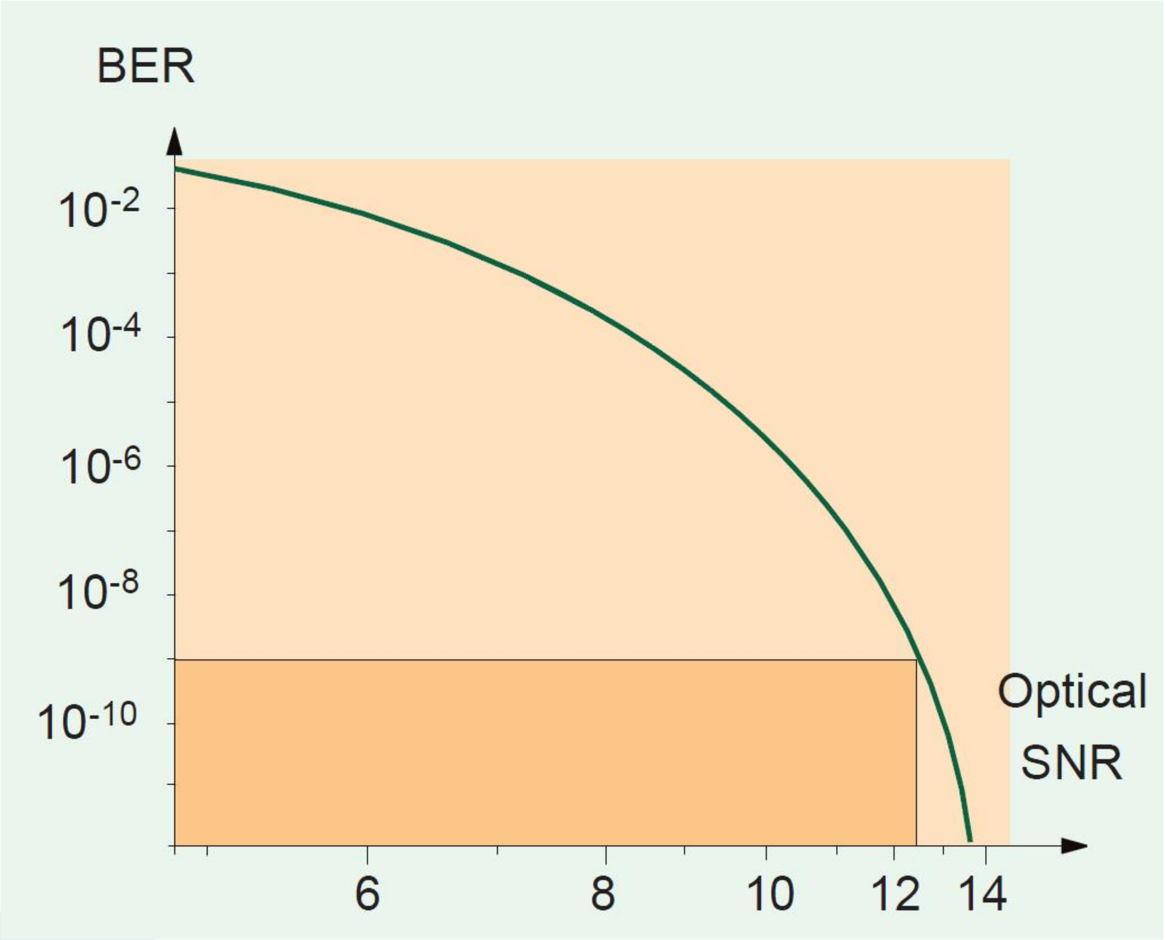
$$\left\langle i_n^2 \right\rangle = 2 \cdot e \cdot I \cdot BW_{PD} = 2 \cdot e \cdot \left(I_S + I_{dark} \right) \cdot BW_{PD}$$

$$P_{\min} = \frac{\sqrt{\left\langle i_n^2 \right\rangle_{\min}}}{r} = \frac{1}{r} \cdot \sqrt{2 \cdot e \cdot I_{dark} \cdot BW_{PD}}$$

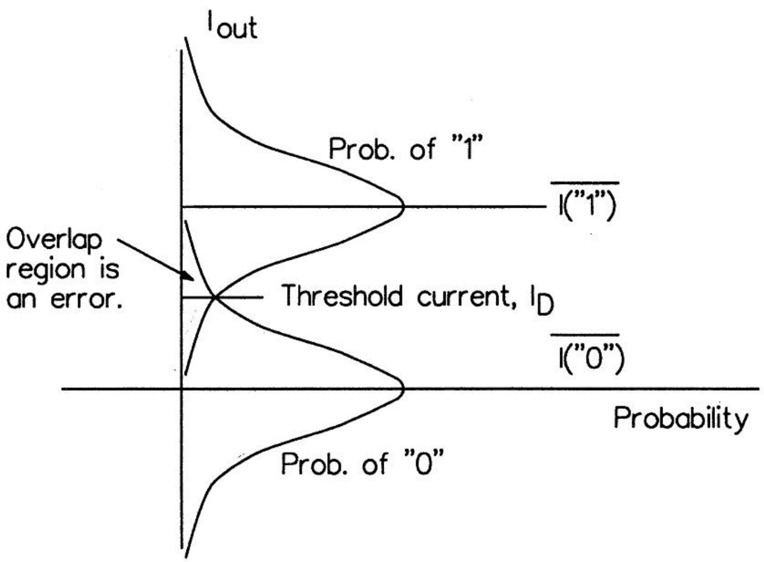
$$NEP[W / \sqrt{Hz}] == \frac{1}{r} \cdot \sqrt{2 \cdot e \cdot I_{dark}}$$

BER

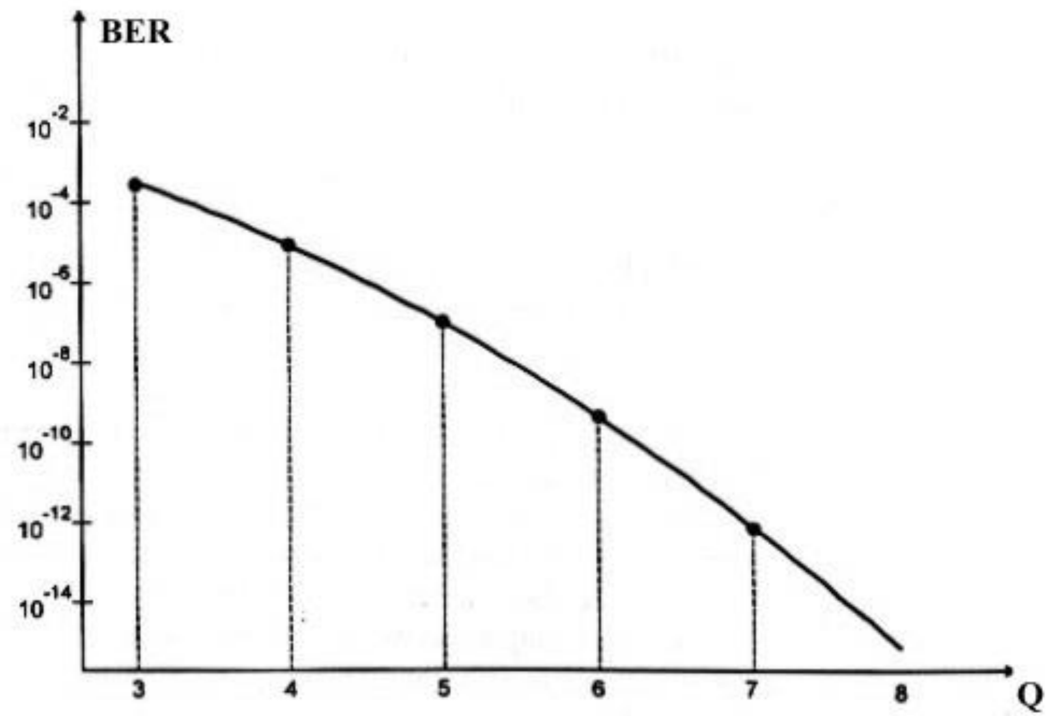
- Bit Error Rate



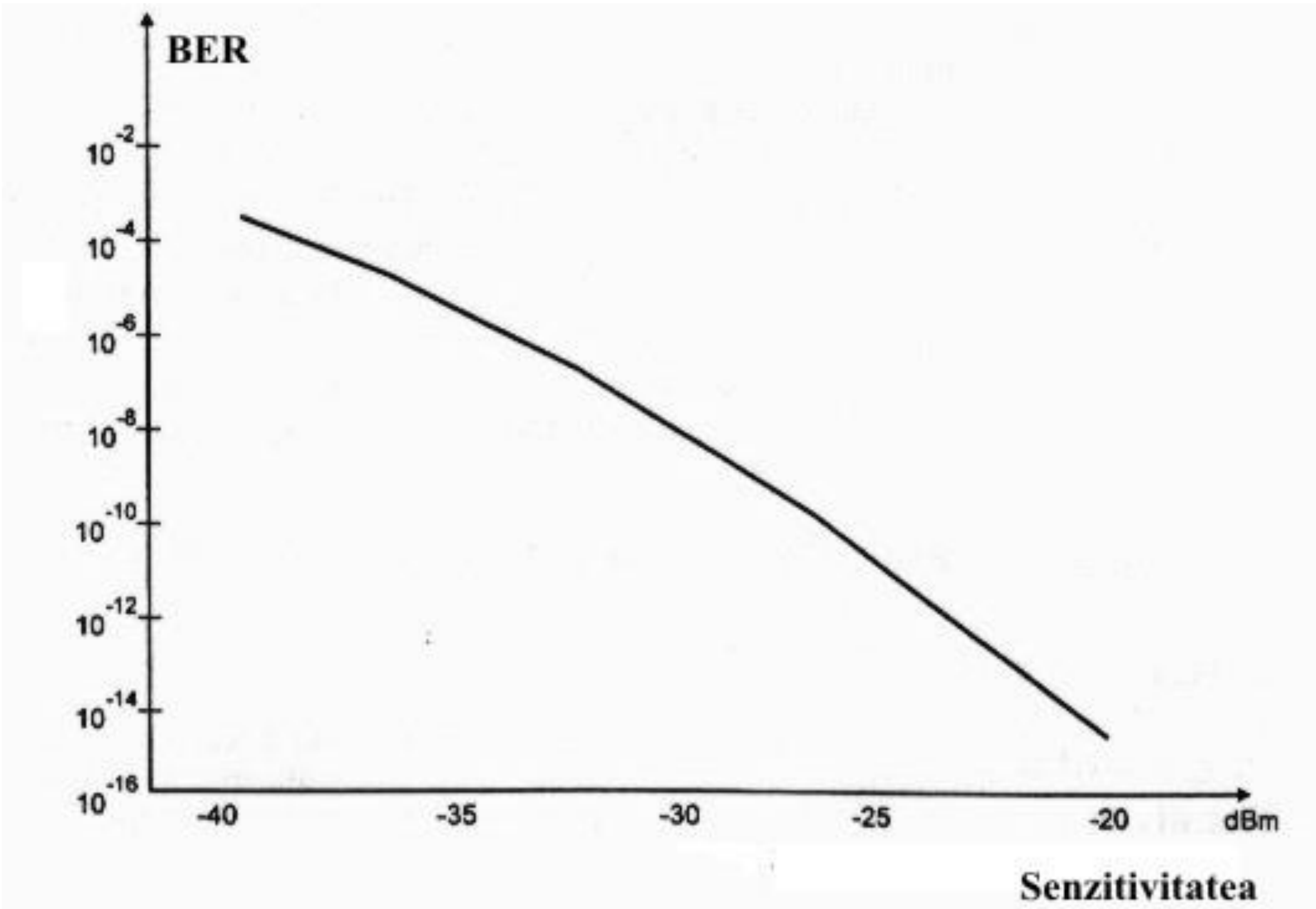
Probabilitate de eroare



$$Q = \frac{\overline{i(1)} - I_D}{\sigma_1} = \frac{I_D - \overline{i(0)}}{\sigma_0}$$



Senzitivitatea unei diode



Contact

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