Optoelectronică

Curs 12

2022/2023

Disciplina 2022/2023

- 2C/1L Optoelectronică OPTO
- **Minim 7 prezente curs + laborator**
- Curs – conf. Radu Damian
  - an IV μE
  - Joi 08(**:10**)-10:00, C1
  - E – 70% din nota (50%+20%)
    - **20% test (VP) la curs**, saptamana 4-6?
  - probleme + (2p prez. curs)
  - toate materialele permise
- Laborator – sl. Daniel Matasaru
  - an IV μE
    - Luni 18-20, Miercuri 11-15 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)
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- **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**

Bibliografie

- http://rf-opto.etti.tuiasi.ro
- Irinel Casian-Botez, "Structuri Optoelectronice", Ed. "CANOVA", Iasi 2001, ISBN 973-96099-2-9
- Behzad Razavi – Design of Integrated Circuits for Optical Communications, Mc Graw Hill
- John Powers – An Introduction to Fiber Optic Systems
- IBM – Understanding Optical Communications: on-line http://www.redbooks.ibm.com
- Radu Damian, I Casian, D Matăsaru – „Comunicatii Optice” , Indrumar de laborator, 2005
- MIT Course – Fundamentals of Photovoltaics, https://ocw.mit.edu

Bonus

Disciplina: Optoelectronica, structuri, tehnologii, circuite
An: 2015/2016

Bonus-uri care se aplica la nota de la teza obtinute prin:
- prezenta la curs (0.5p / 3pr)
- 3 miniteste aplicate la curs (max. 3 X 1.5p)
- contributie la site rf-opto (foto <C5=1p, >C5=0.5p)

Nr.	Student	Grupa	Prezente curs	Bonus prezenta	Bonus foto	Bonus T1	Bonus T2	Bonus T3	Total Bonus	Obs.
1	CIOLPAN OCTAVIAN	5306	3	0.5					0.5	-
2	NITA COSTEL-CATALIN	5307	4	0.5	1				1.5	-
3	BARON BOGDAN-IONUT	5405	12	2	1	0.5		0.75	4.25	-

Prezenta

Curs
Laborator

Liste

Studenti care nu pot intra in examen
Bonus-uri acumulate

- **Minim** 7 prezente
- 0.5p/3(2)prez
- 3 teste
- foto <C3/<C5

LED

Dioda electroluminescenta
Capitolul 7

Cuprins

- **Lumina ca undă electromagnetică** (ecuaţiile lui Maxwell, ecuaţia undelor, parametrii de propagare)
- **Elemente de fotometrie şi radiometrie** (mărimi energetice/luminoase)
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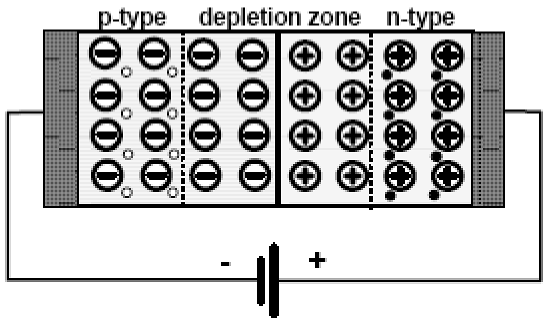
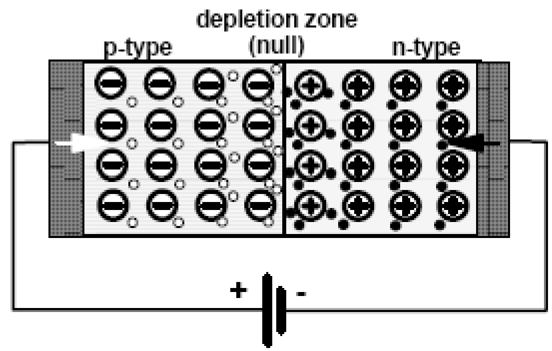
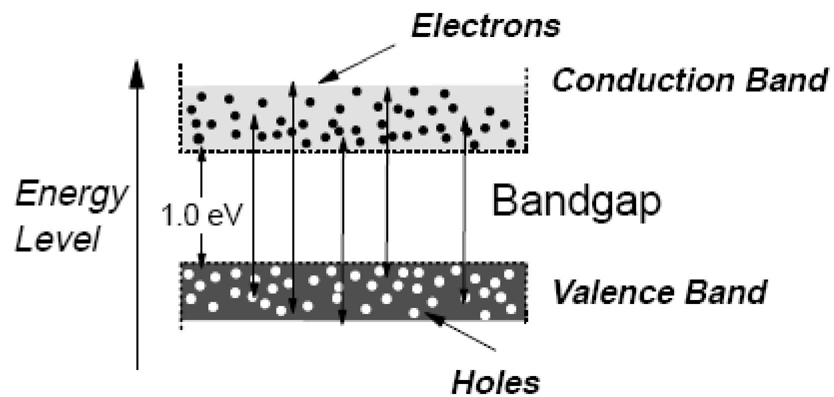
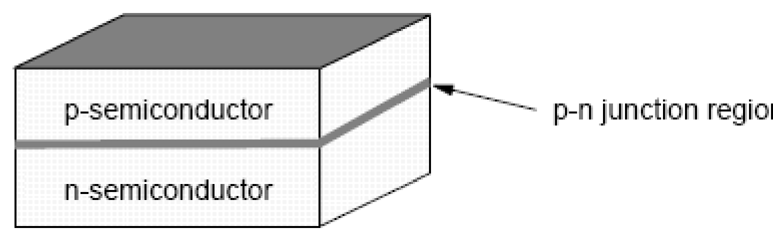
LED – Principiul de operare

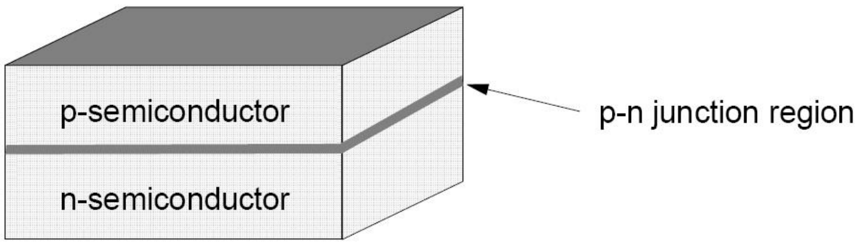


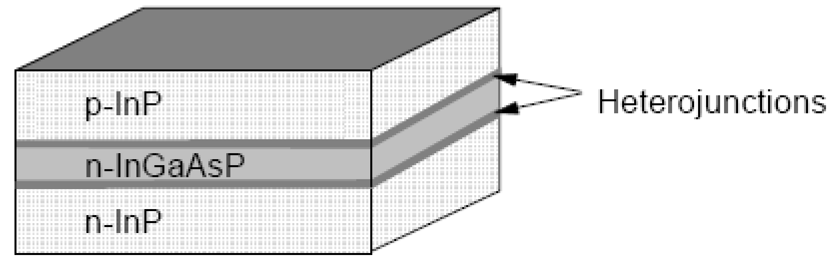




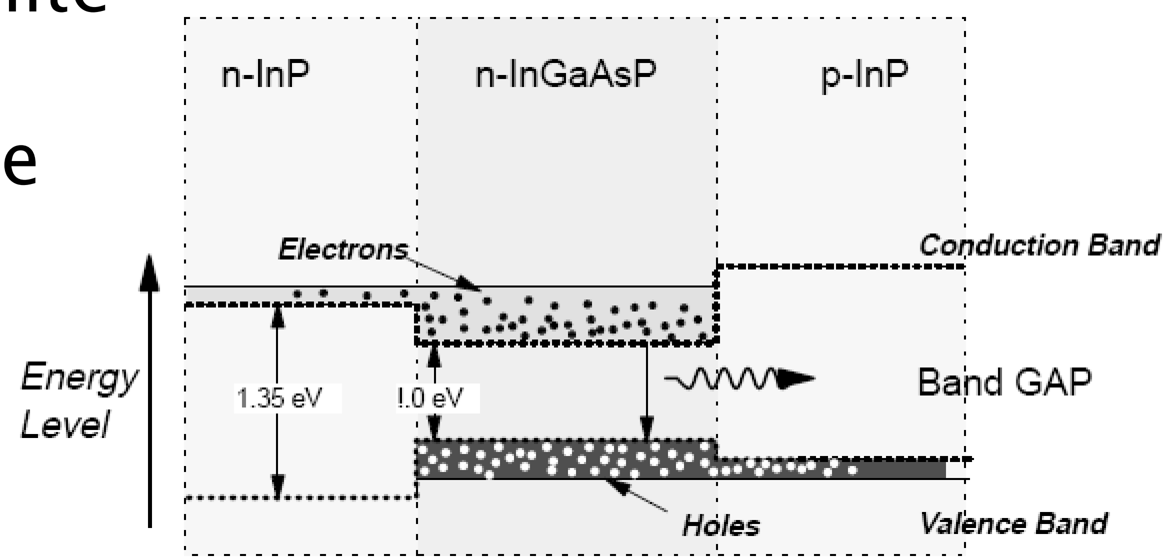


LED cu heterojuncţiuni – principiu





- Structura de nivele energetice permite capturarea purtatorilor intre cele doua heterojonctiuni

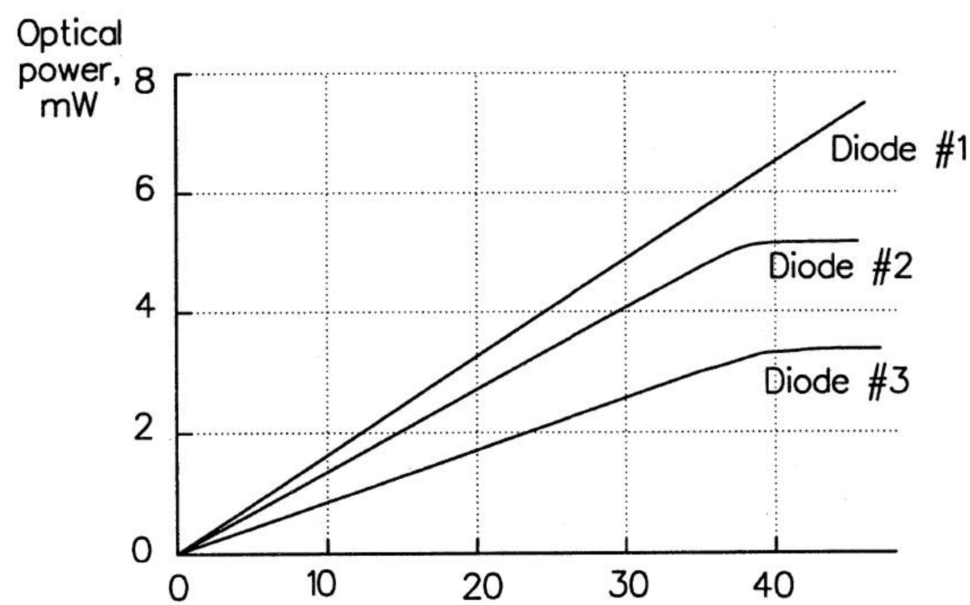


Caracteristica de raspuns a LED-urilor

- Caracteristica putere optica emisa functie de curentul direct prin LED este liniara la nivele mici ale curentului.
- Nu exista curent de prag
- La nivele foarte mari puterea optica se satureaza
- Responzivitatea

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

- Tipic r=50μW/mA



Dioda Laser

Capitolul 8

Cuprins

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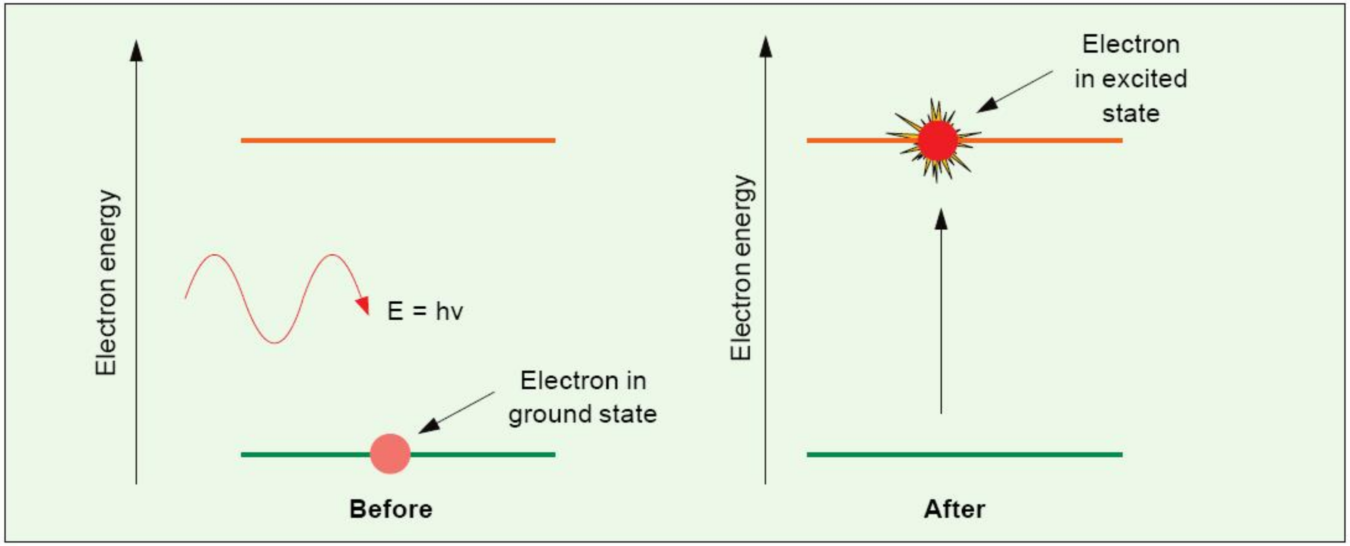
Caracteristici dioda laser

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

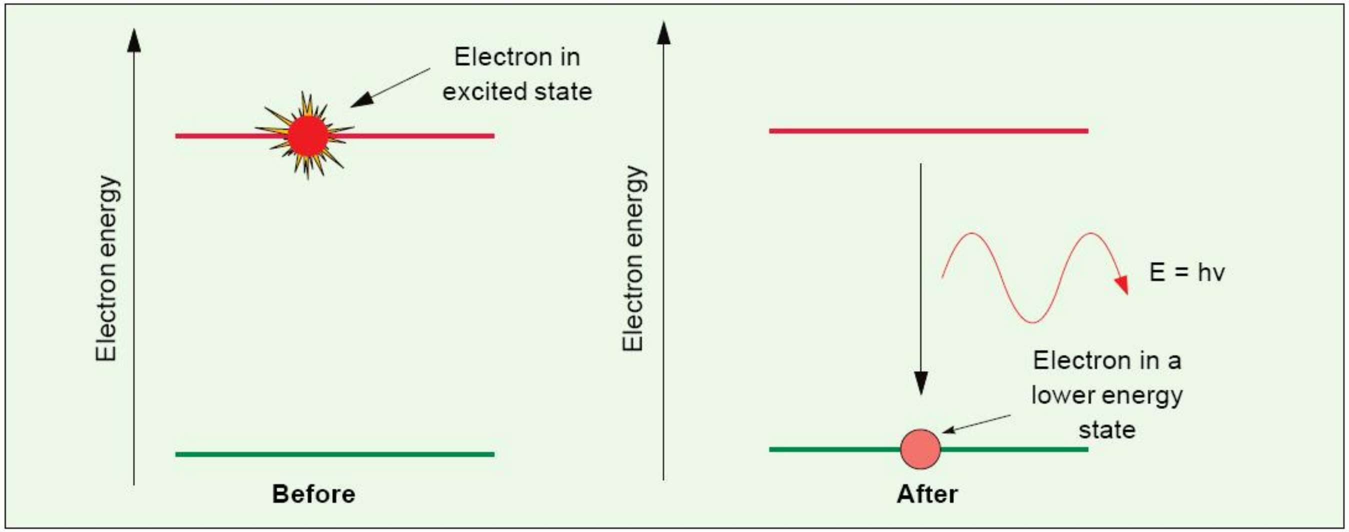
Dioda LASER – Principiu de operare

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



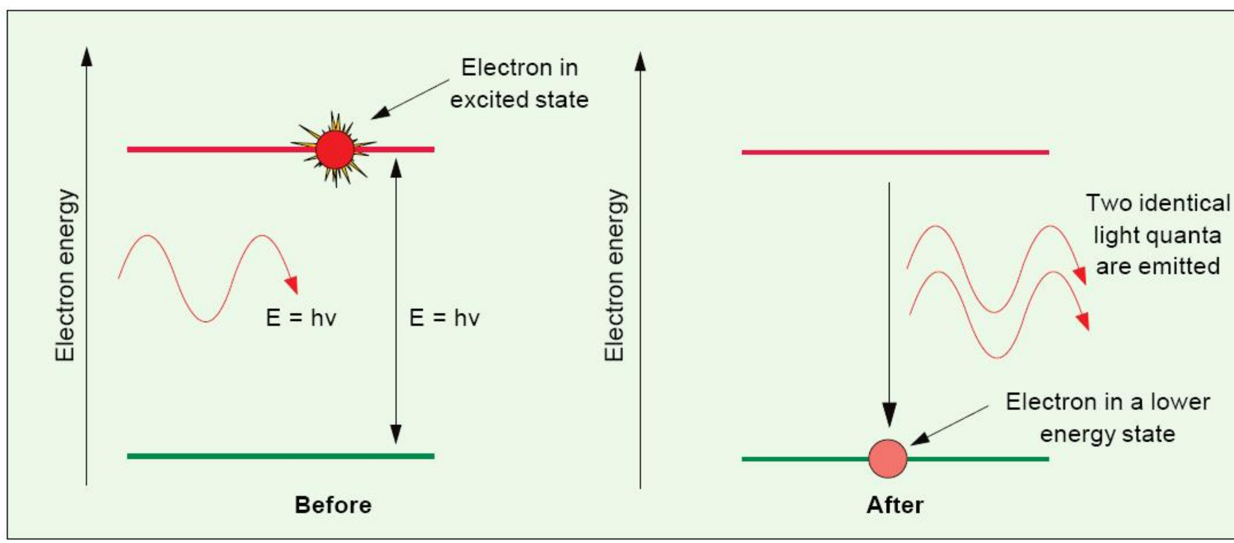
Dioda LASER – Principiu de operare

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



Dioda LASER – Principiu de operare

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



Caracteristici curent tensiune

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

$I < I_{th}$ regim LED

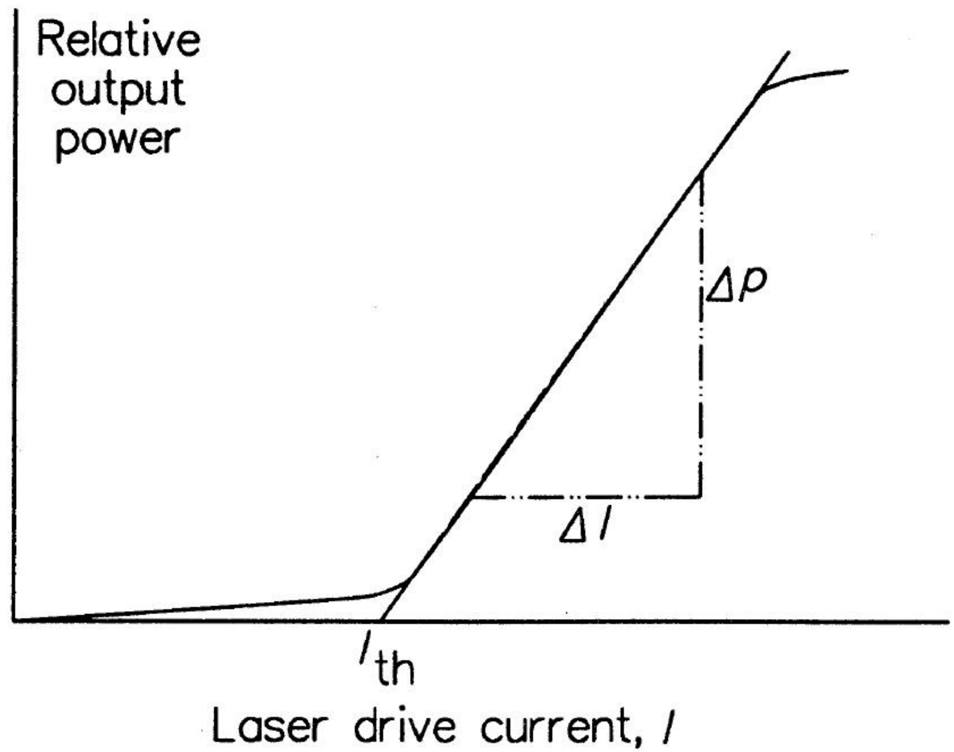
ineficient!, $P_o \cong 0$

$I > I_{th}$ regim LASER

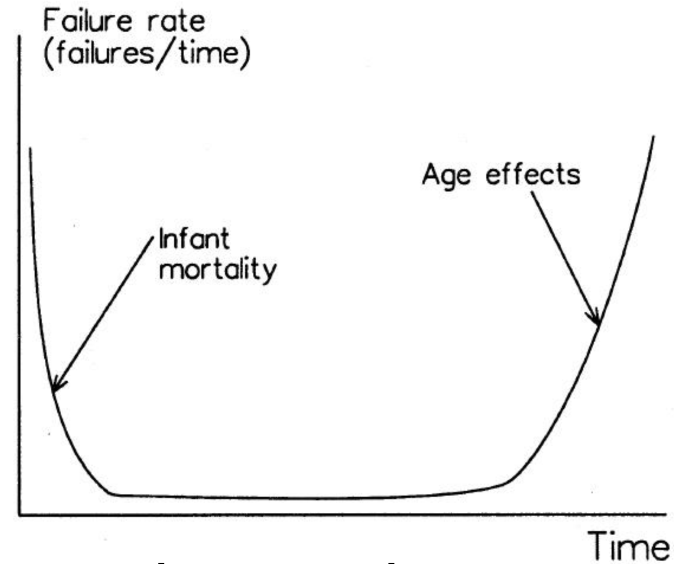
$$r = \frac{\Delta P_o}{\Delta I} \quad \left[\frac{W}{A}\right]$$

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

Apare saturare la nivele mari de curent



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

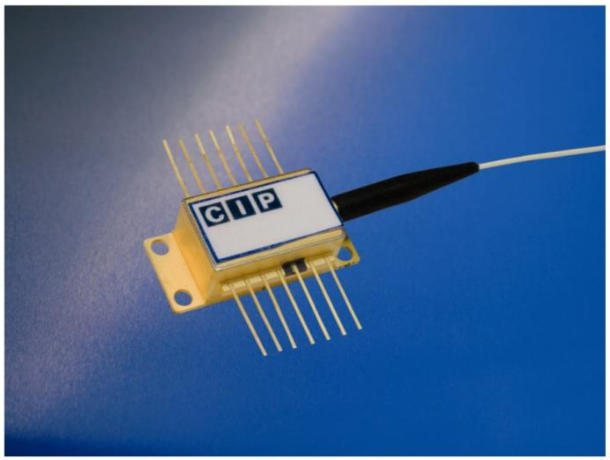
- eficienta de conversie electro-optic (randament)

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

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

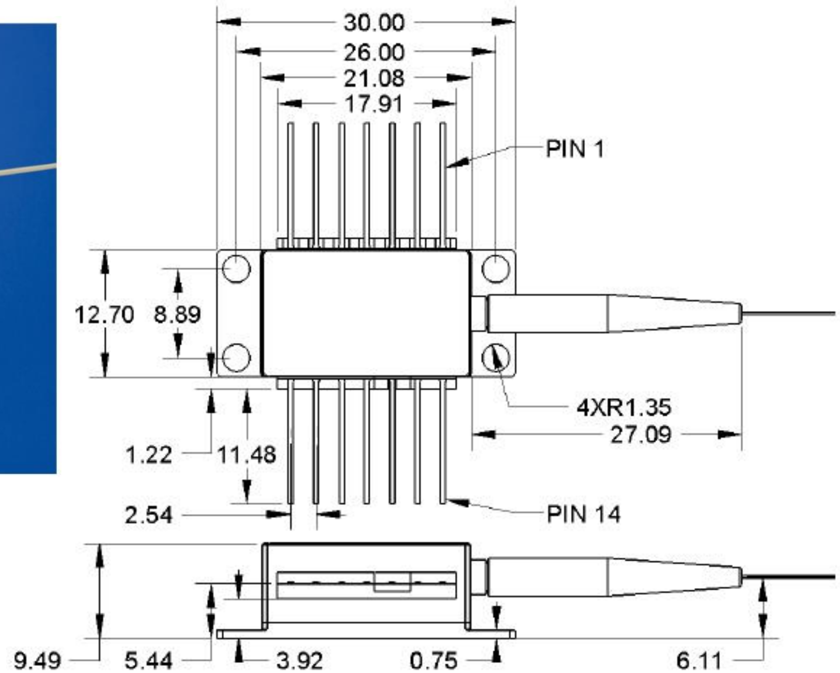
$$\eta = \frac{n_f}{n_e} \qquad \eta = \frac{\Delta P / h\nu}{\Delta I / e} = r \cdot \frac{e}{h\nu}$$

1550nm DFB Laser



Mechanical Drawing

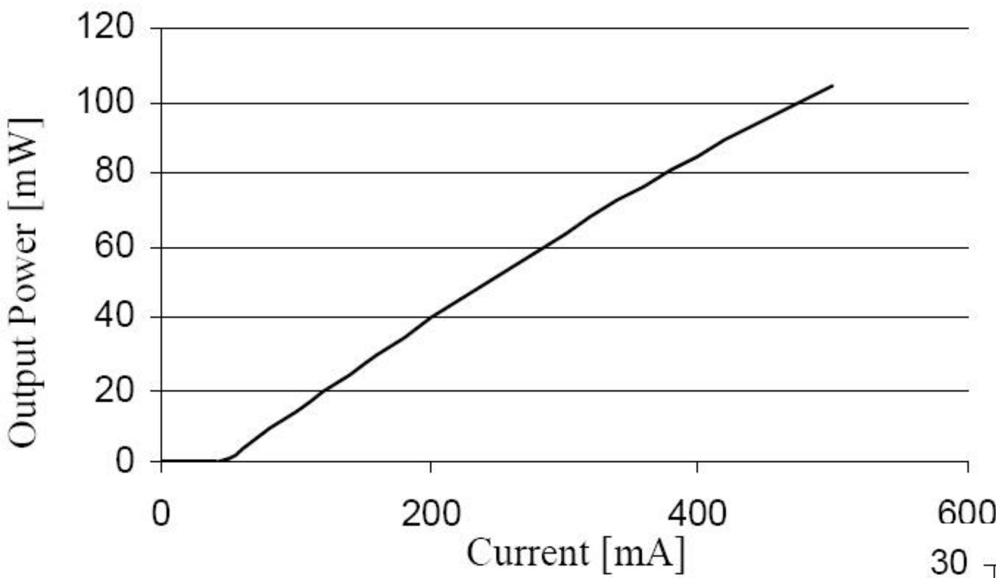
All units in mm

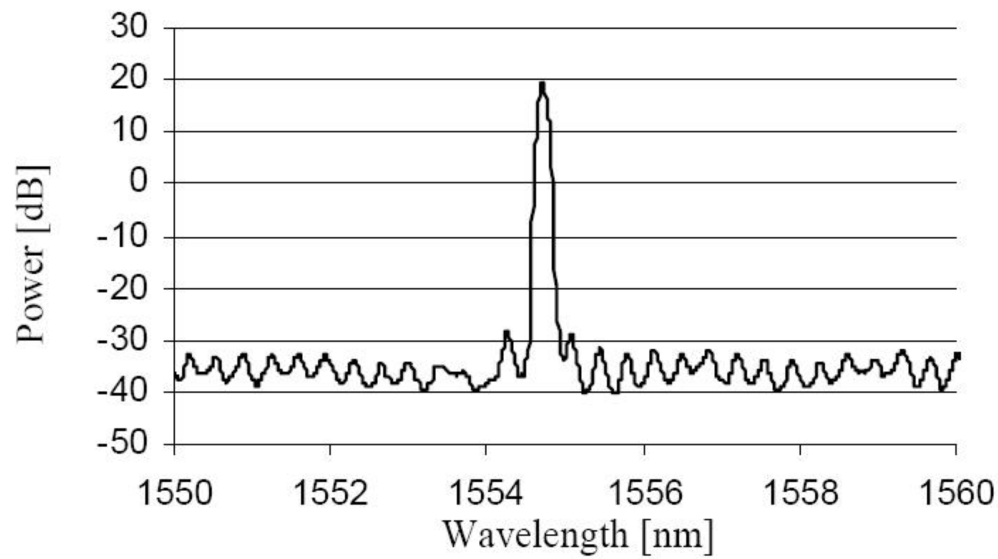


Pin out

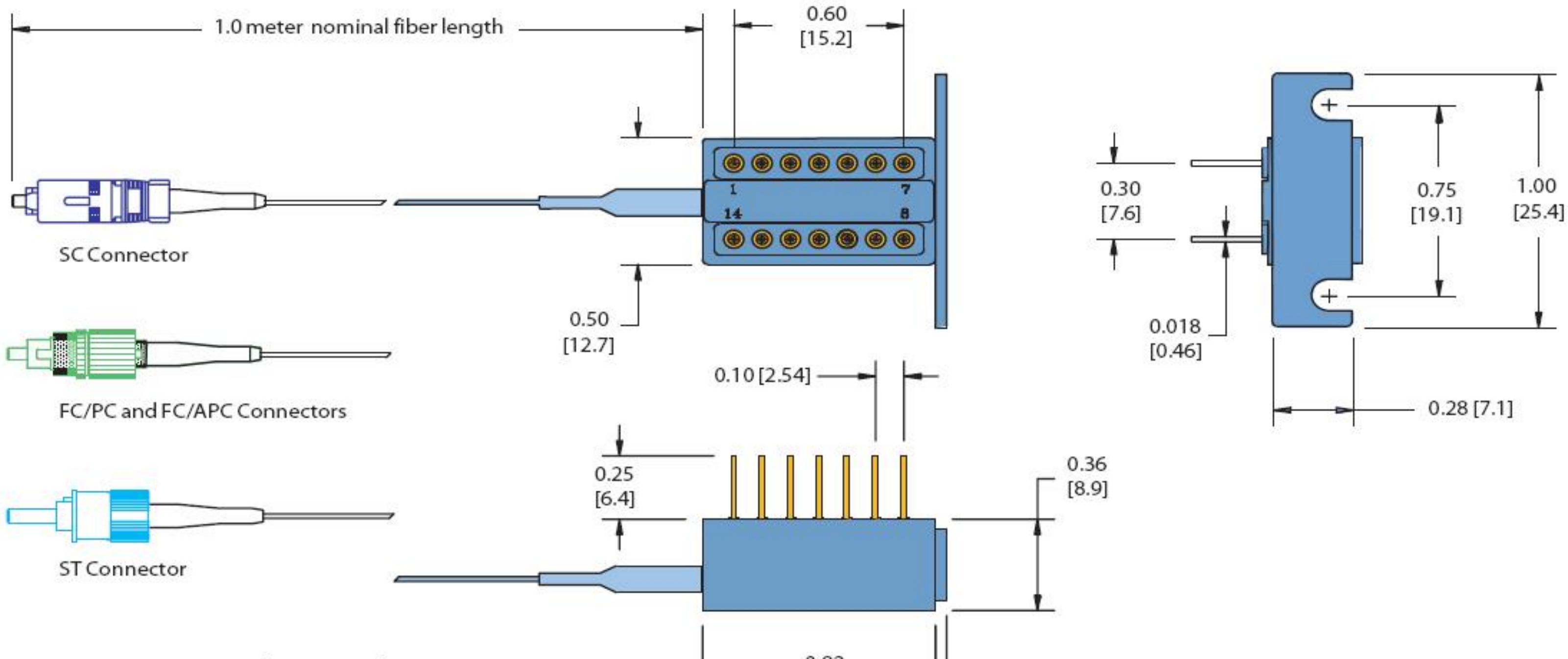
Pin	Description
1	Thermistor
2	Thermistor
3	Laser Cathode (Bias)
4	Monitor PD Anode
5	Monitor PD Cathode
6	TEC +
7	TEC -
8	Case GND, Laser Anode
9	Case GND, Laser Anode
10	Case GND, Laser Anode
11	Case GND, Laser Anode
12	Laser Cathode (modulation)
13	Case GND, Laser Anode
14	Case GND, Laser Anode

1550nm DFB Laser

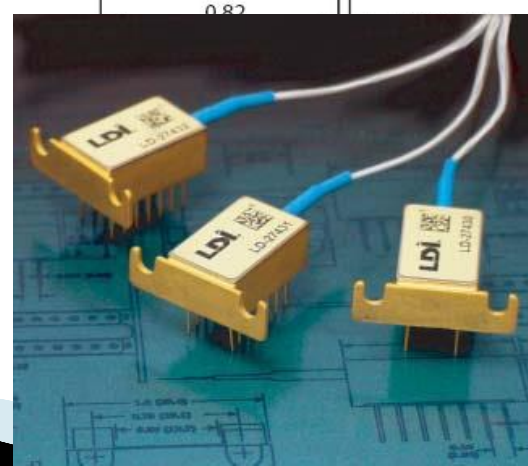


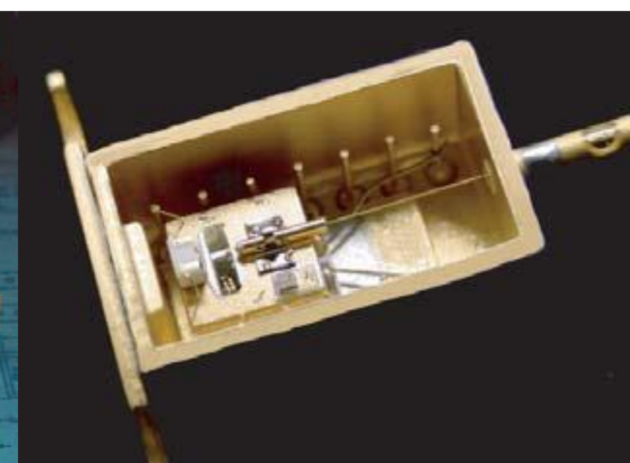


1550nm MQW Laser

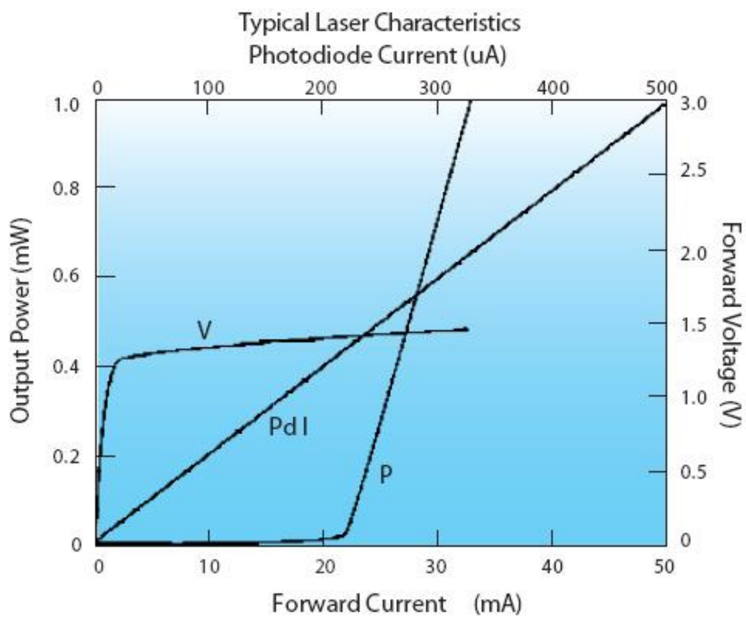


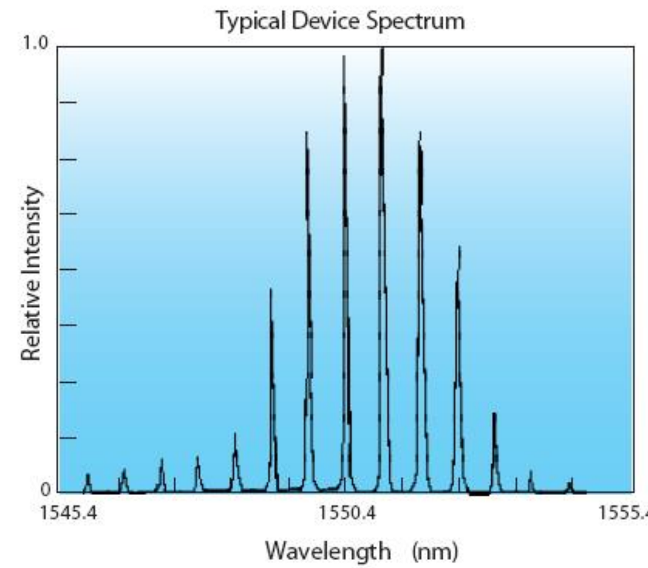
Note: Connectors are not drawn to scale.





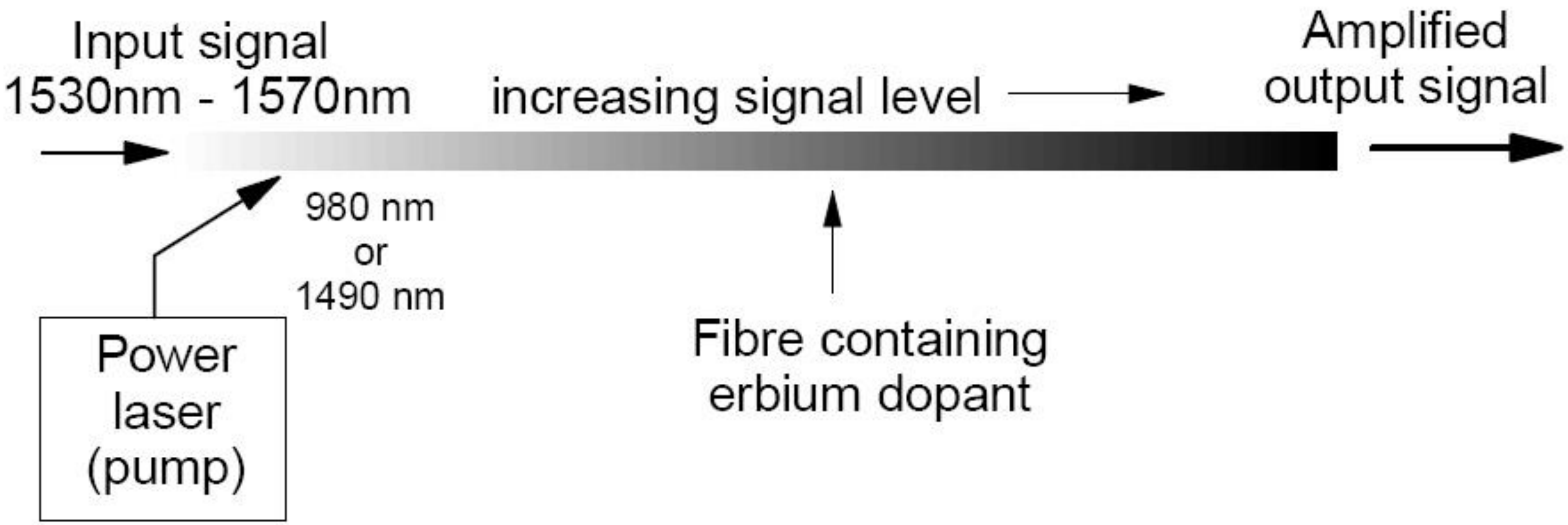
1550nm MQW Laser



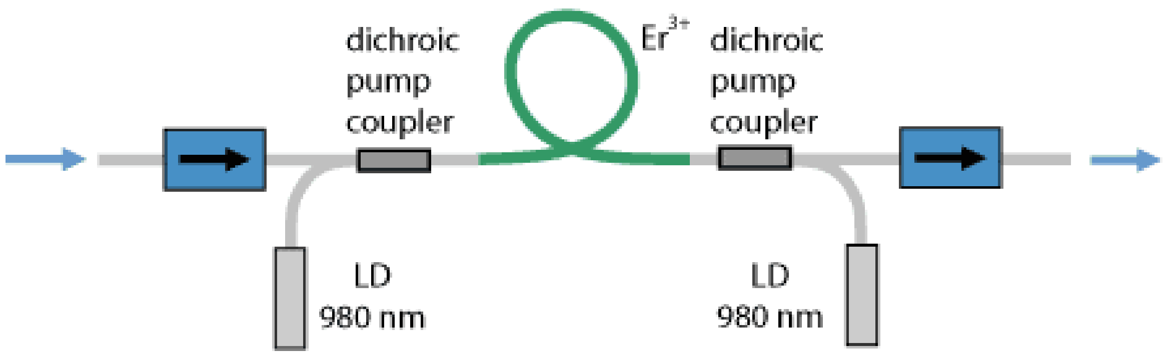


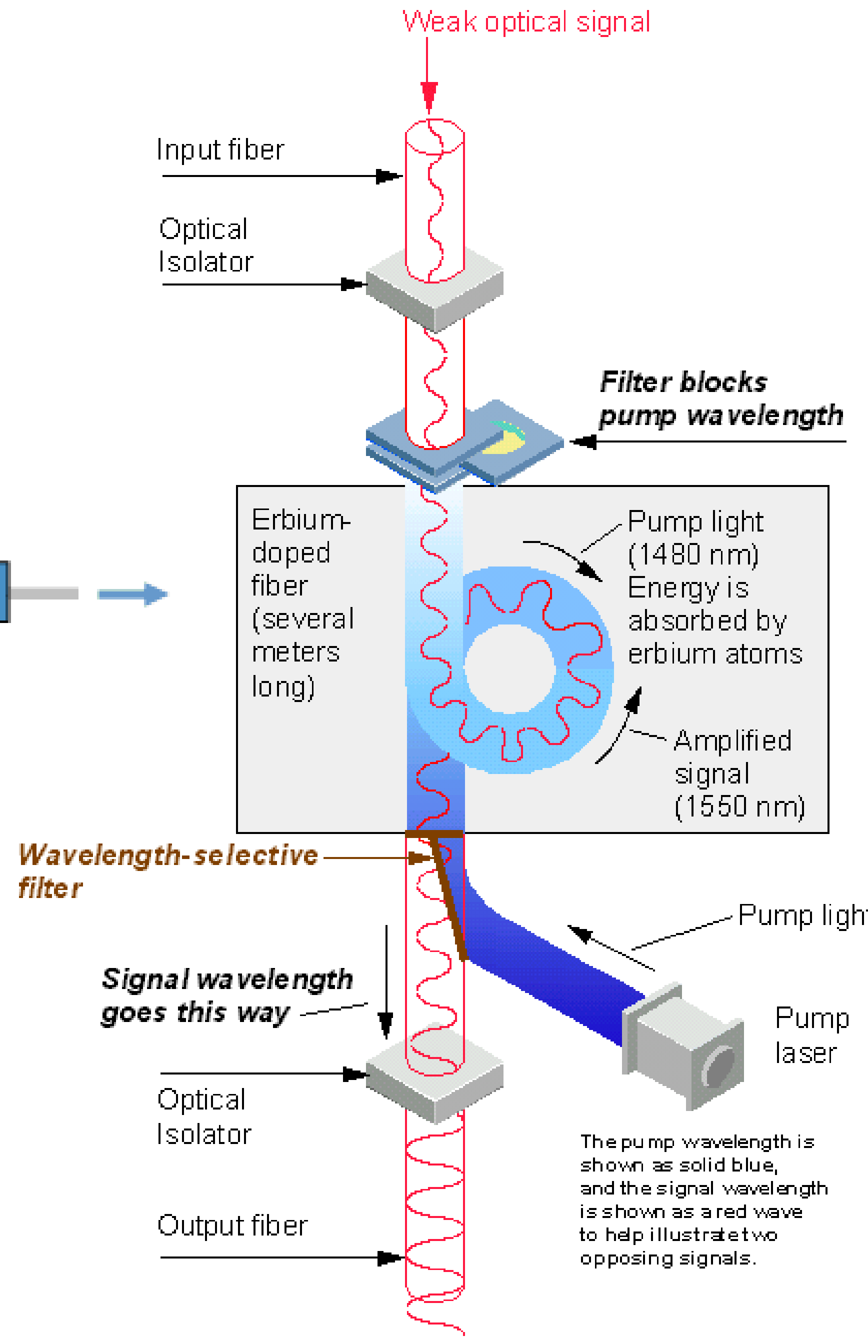
EDFA

- Erbium Dopped Fiber Amplifier

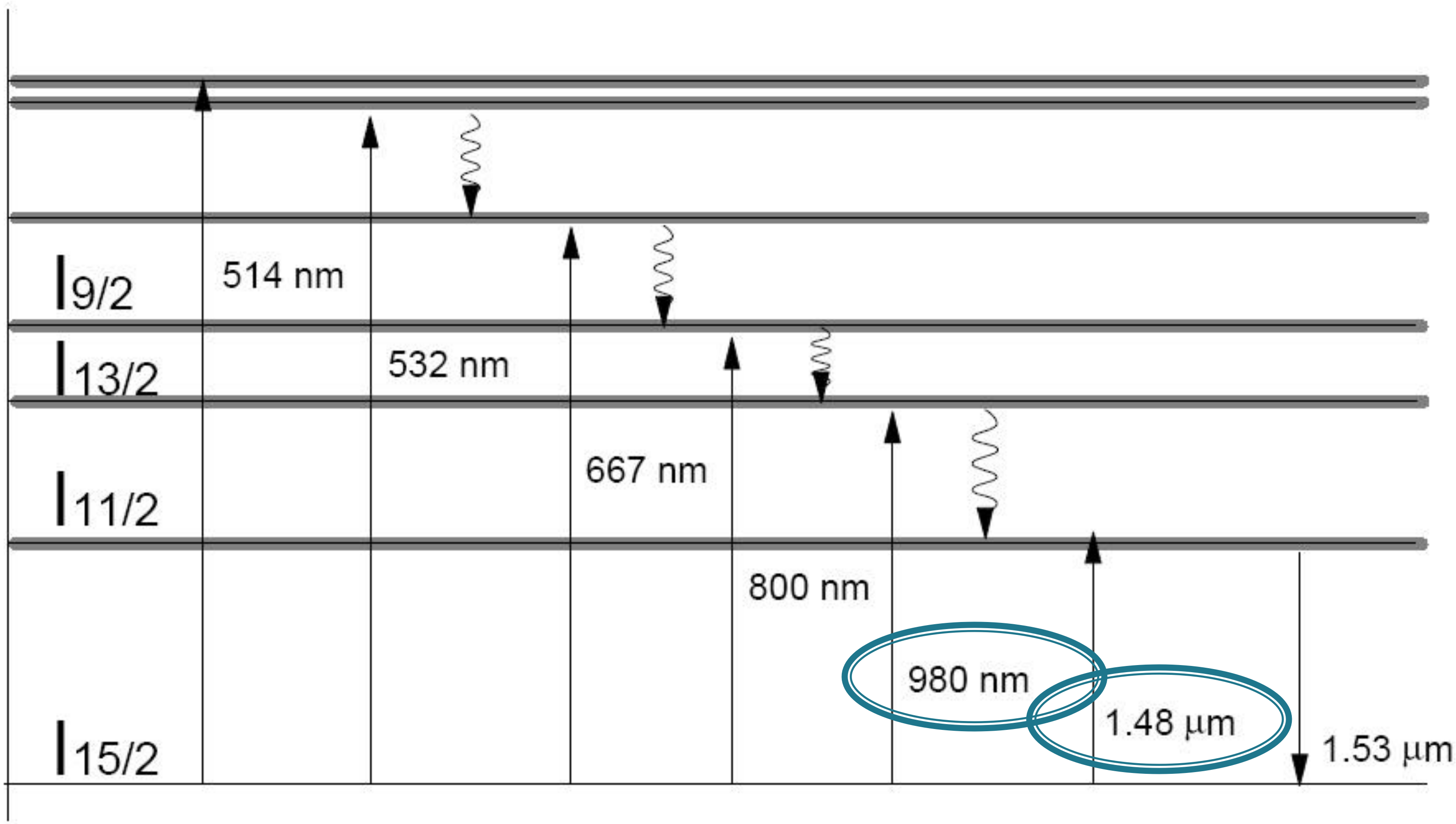


EDFA


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

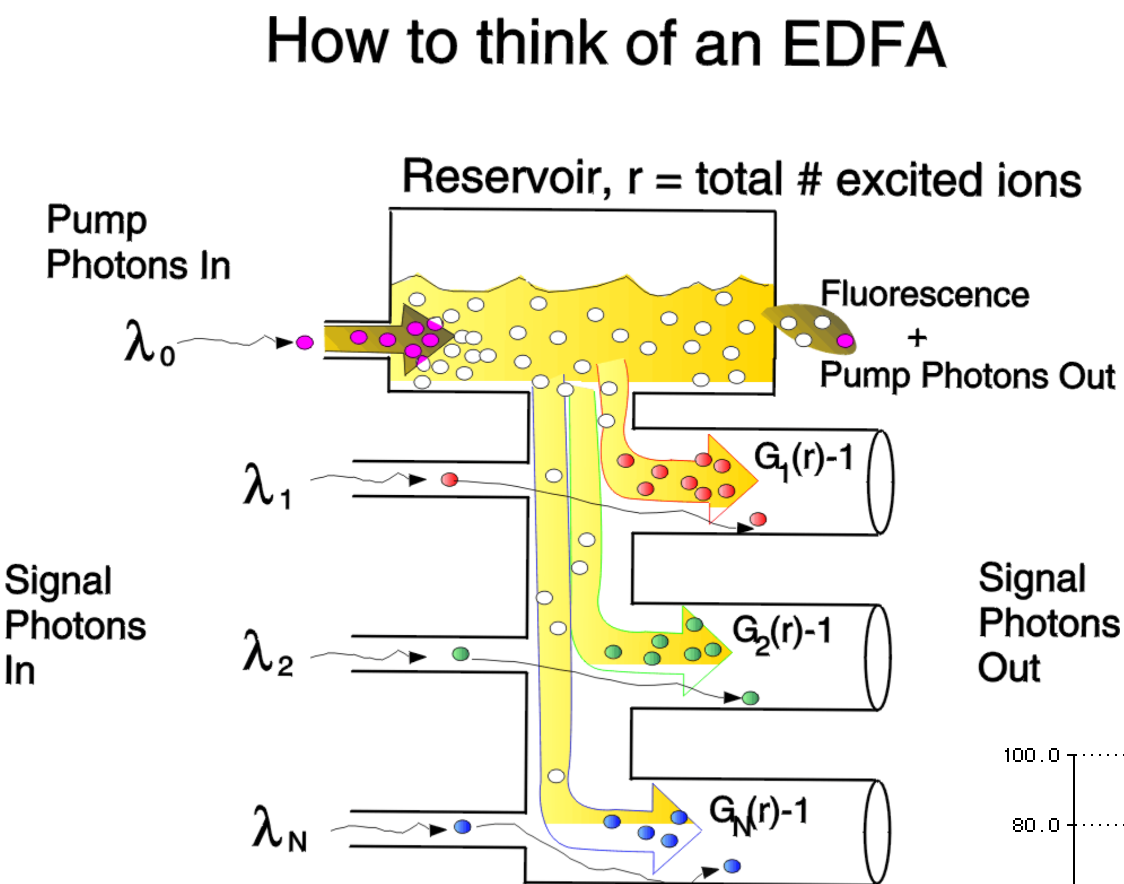

Weak optical signal
Input fiber
Optical Isolator
Filter blocks pump wavelength
Erbium-doped fiber (several meters long)
Pump light (1480 nm) Energy is absorbed by erbium atoms
Amplified signal (1550 nm)
Wavelength-selective filter
Pump light
Signal wavelength goes this way
Pump laser
Optical Isolator
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.

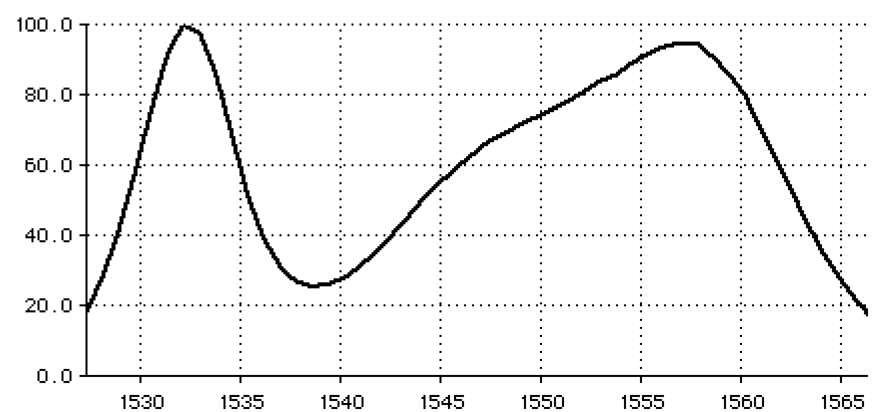
EDFA



$I_{9/2}$
$I_{13/2}$
$I_{11/2}$
$I_{15/2}$
514 nm
532 nm
667 nm
800 nm
980 nm
1.48 μm
1.53 μm

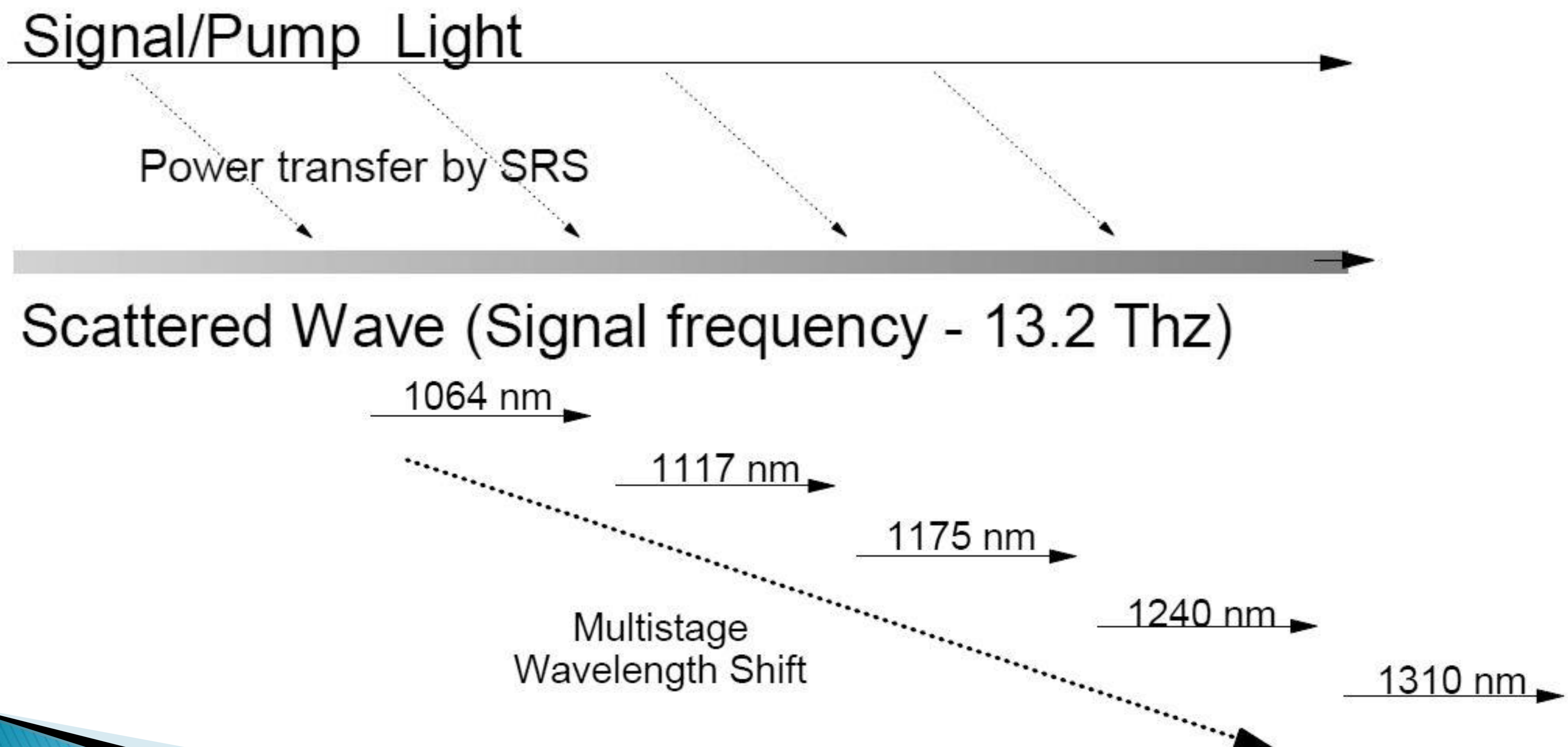
EDFA


How to think of an EDFA
Reservoir, r = total # excited ions
Pump
Photons In
λ0
Fluorescence
+
Pump Photons Out
λ1
G1(r)-1
Signal
Photons
In
λ2
G2(r)-1
λN
GN(r)-1
Signal
Photons
Out

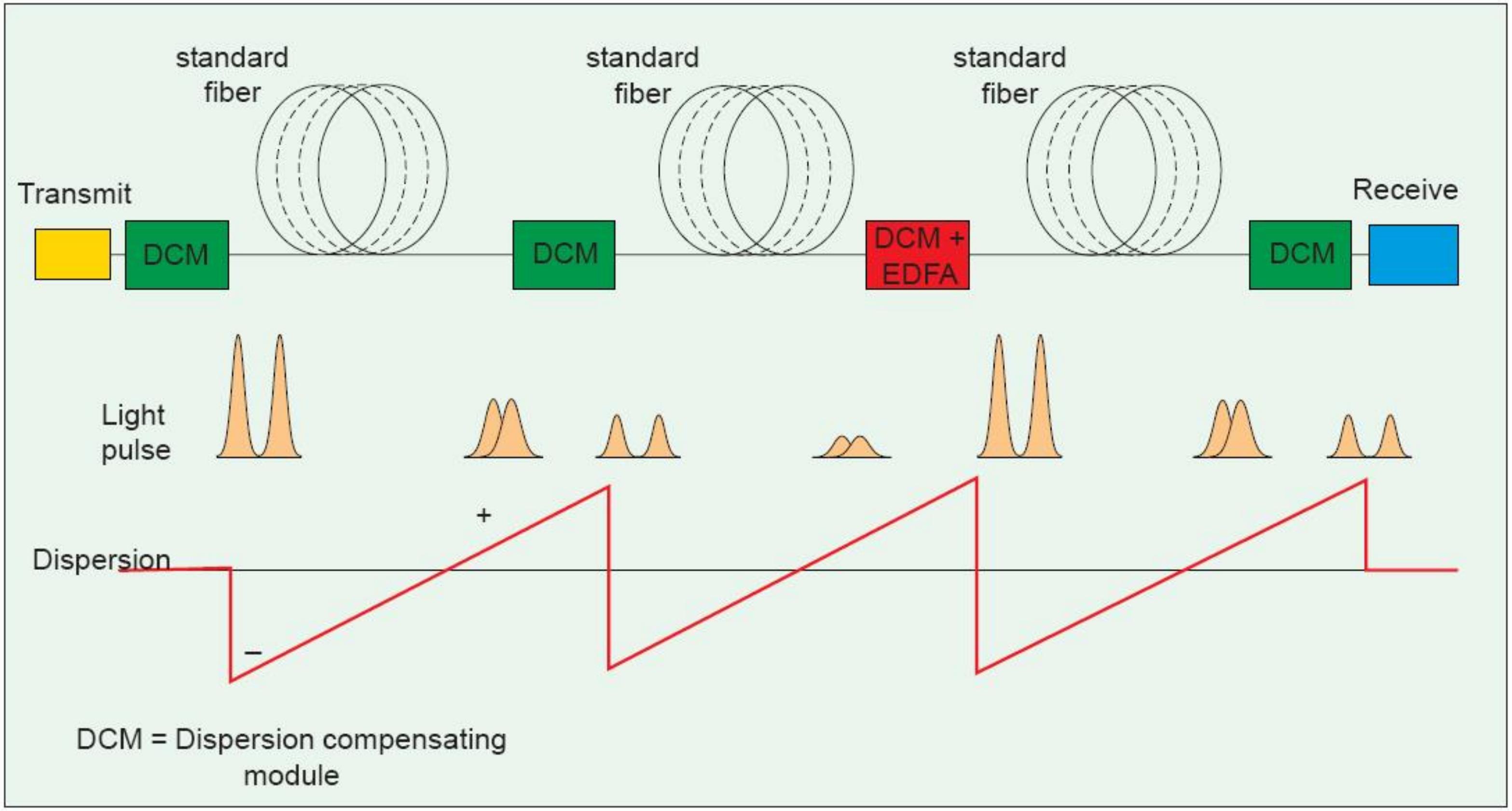

100.0
80.0
60.0
40.0
20.0
0.0
1530
1535
1540
1545
1550
1555
1560
1565

Amplificator cu efect Raman

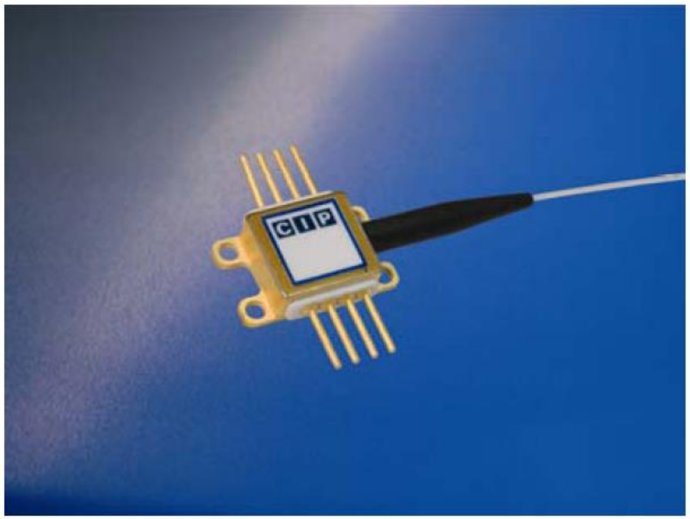
- Bazat pe efect Raman

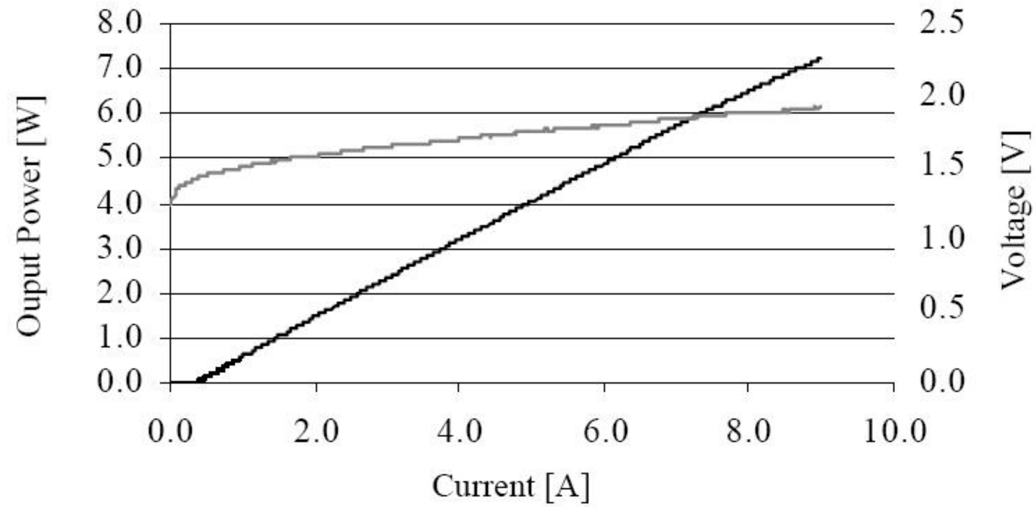


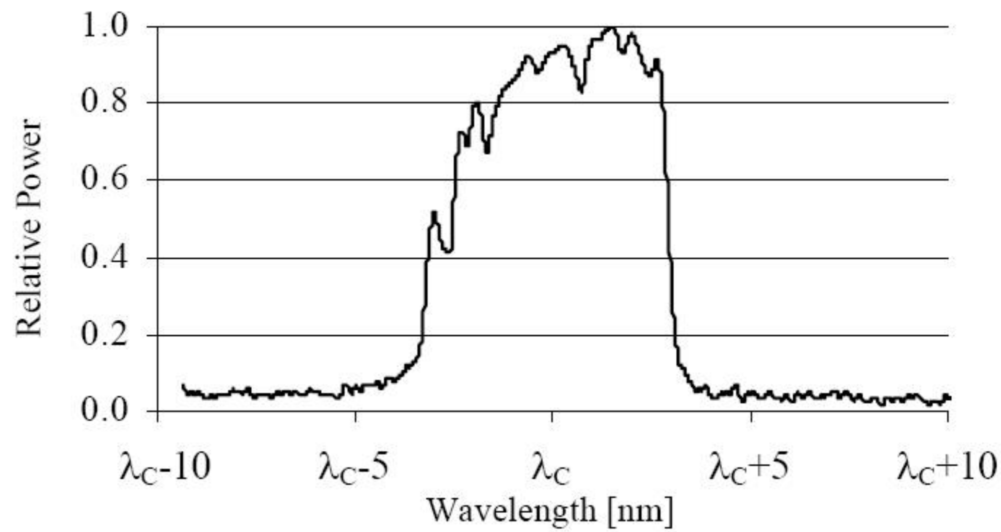
Utilizare amplificatoare optice



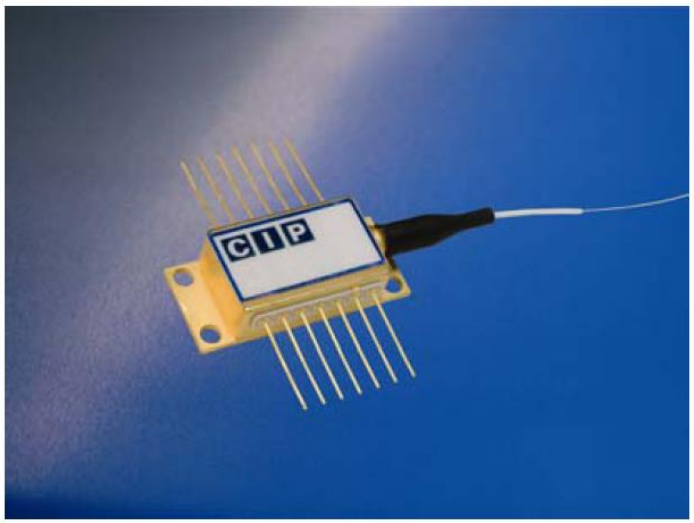
7W 980 nm Multimode Pump Laser

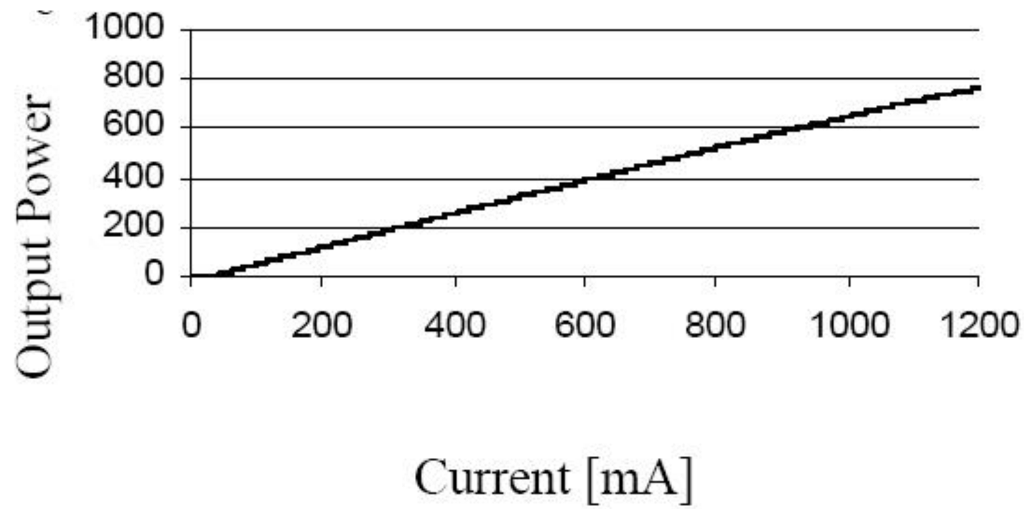


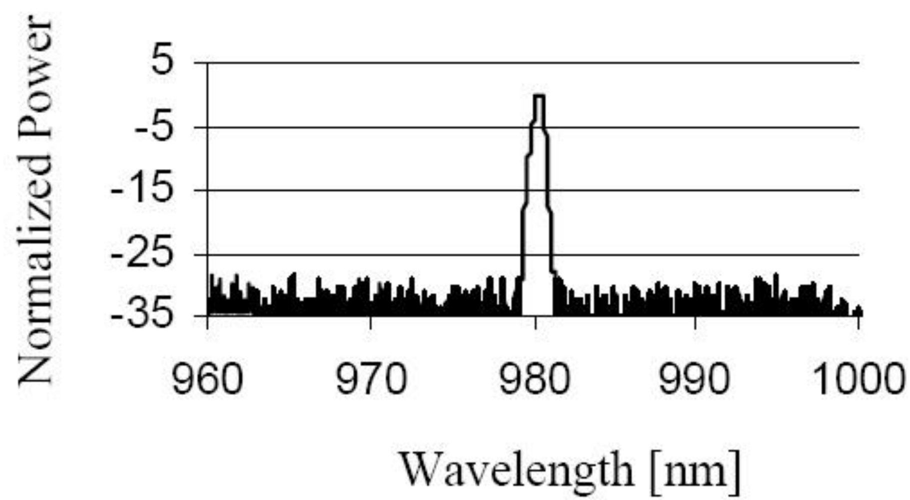




600mW 980 nm Singlemode Pump Laser

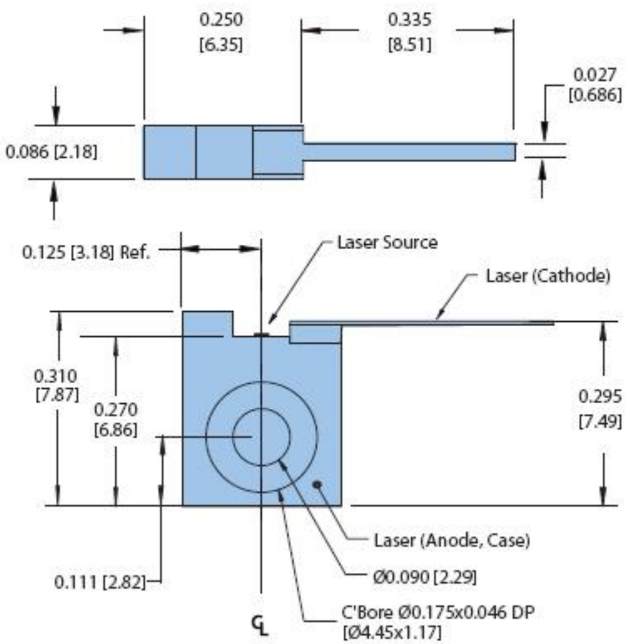




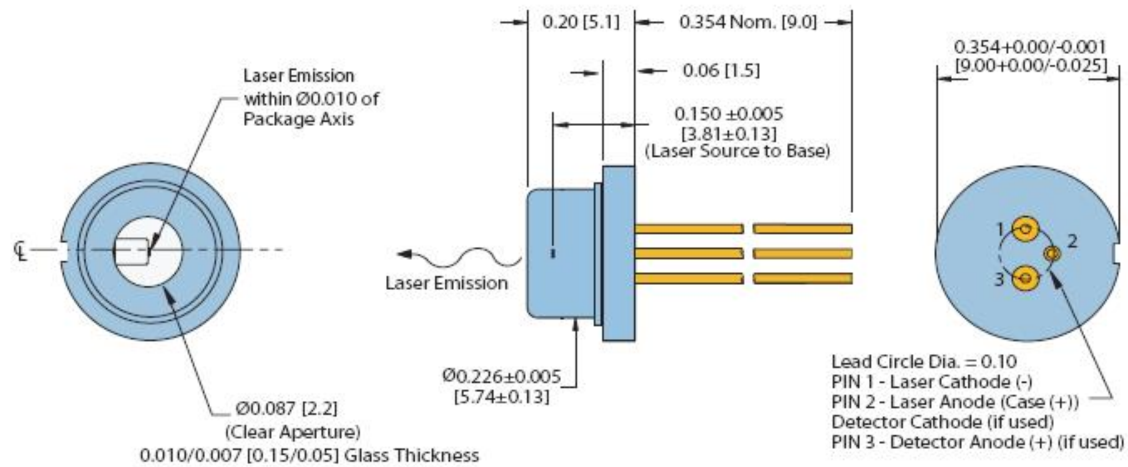


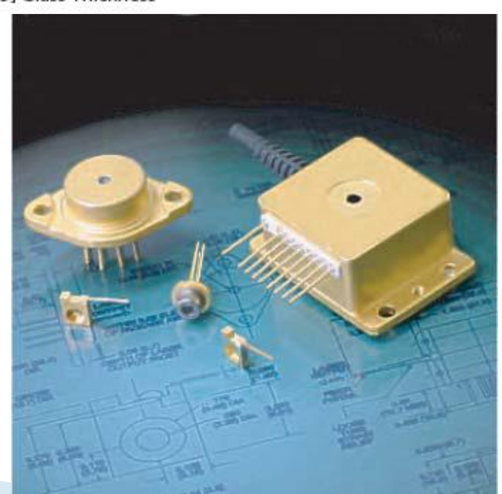
6 W, CW, 800nm

C-Mount Package



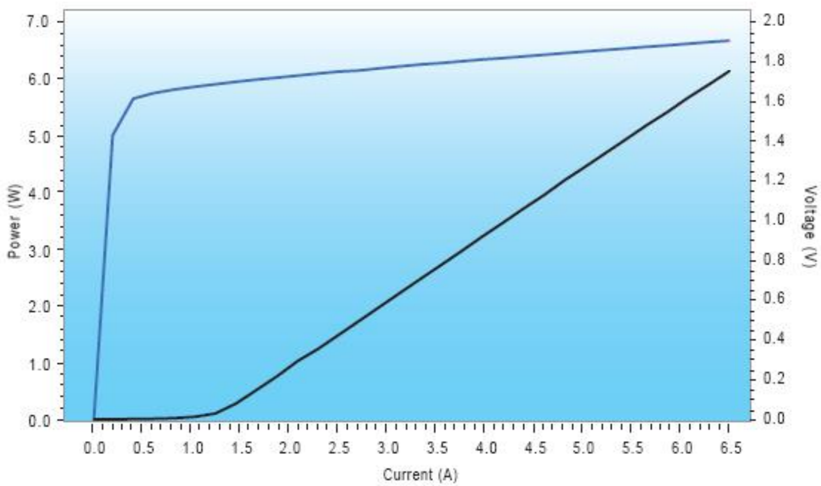
9mm Package



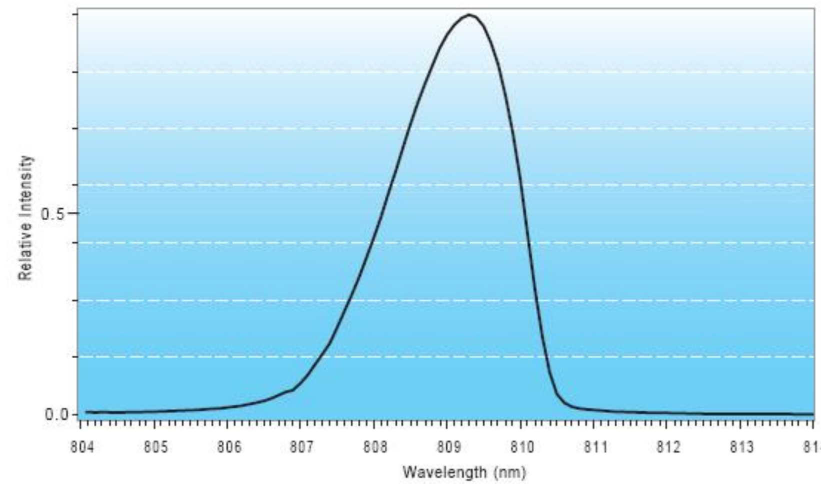


6 W, CW, 800nm

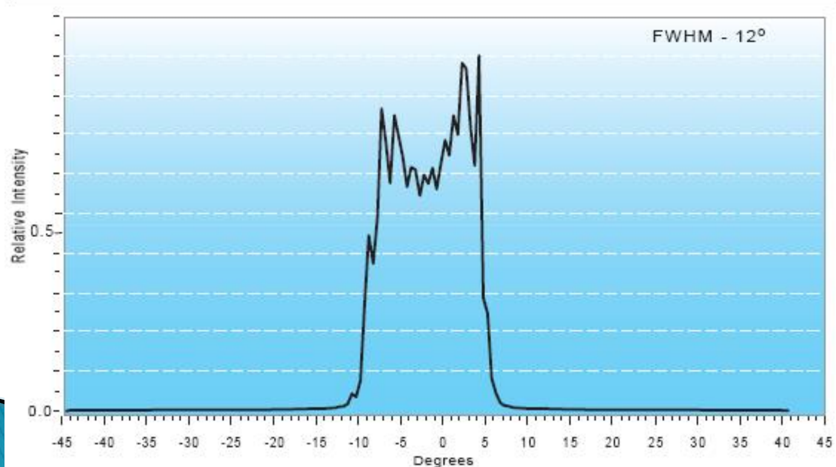
Typical L/I, V/I Graph



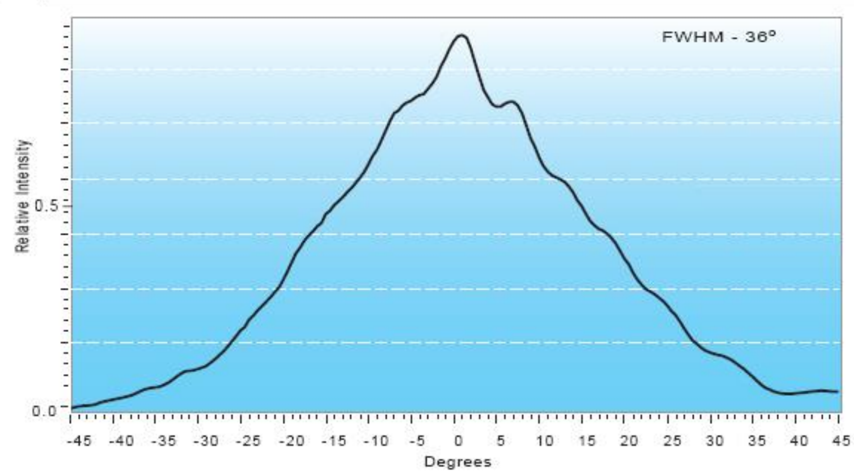
Wavelength Distribution



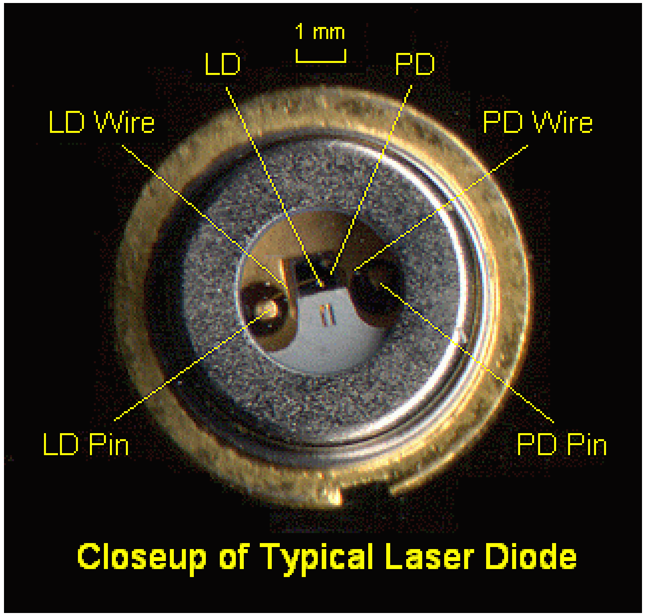
Typical Beam Divergence **Parallel**

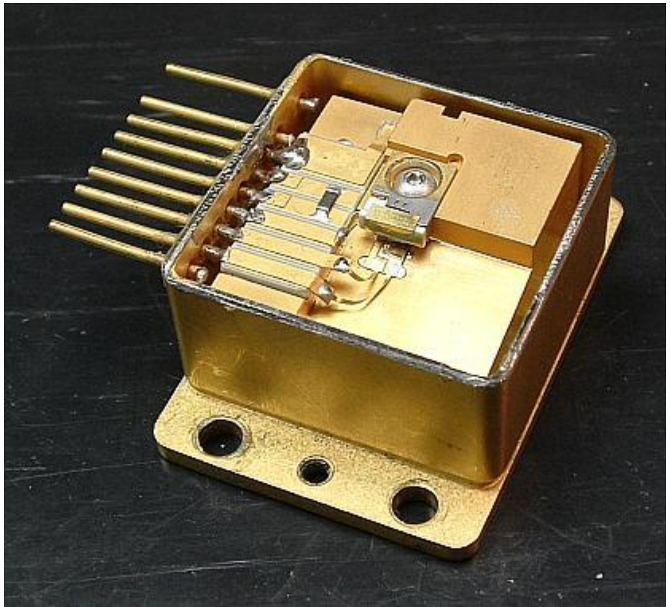


Typical Beam Divergence **Perpendicular**



CW Laser, 650 nm

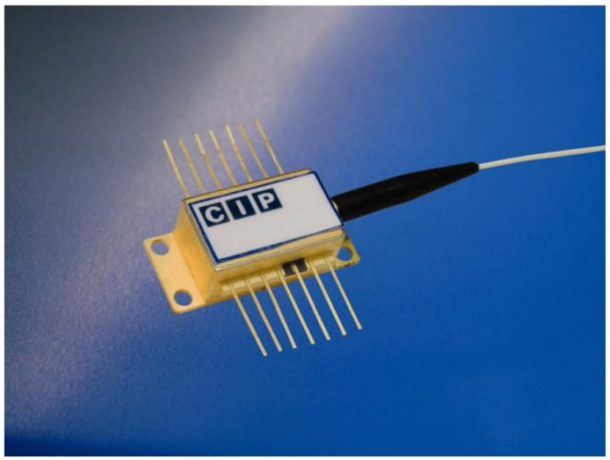


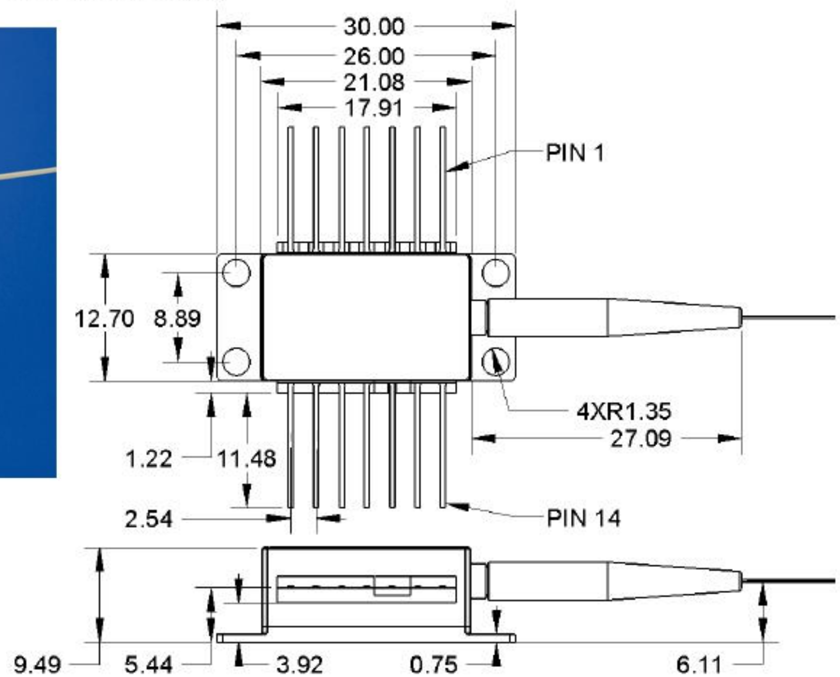


Lungimi de unda

- **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: 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

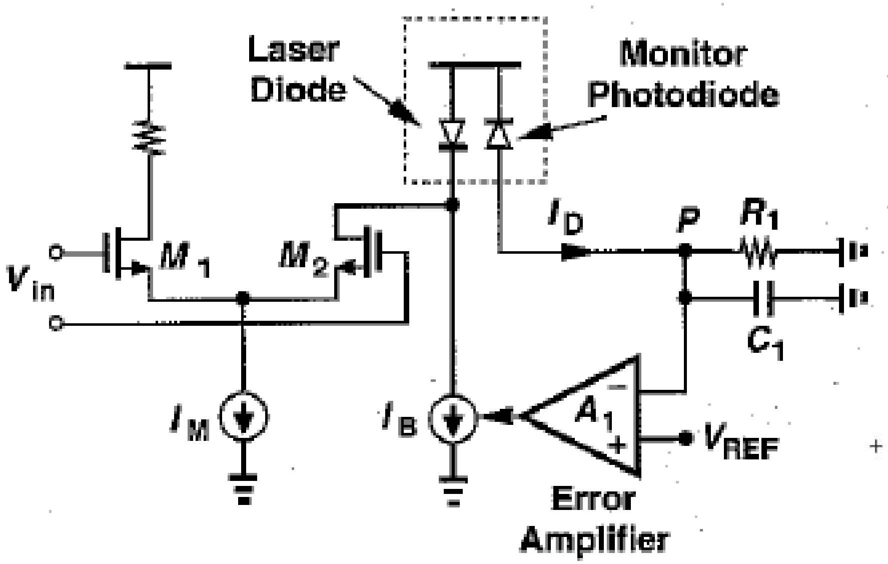




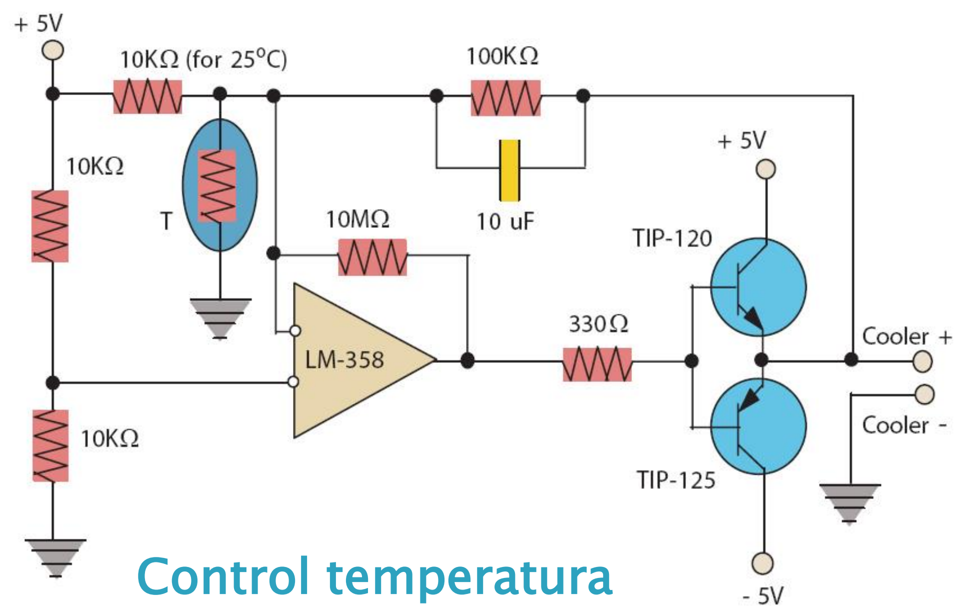
Pin out

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



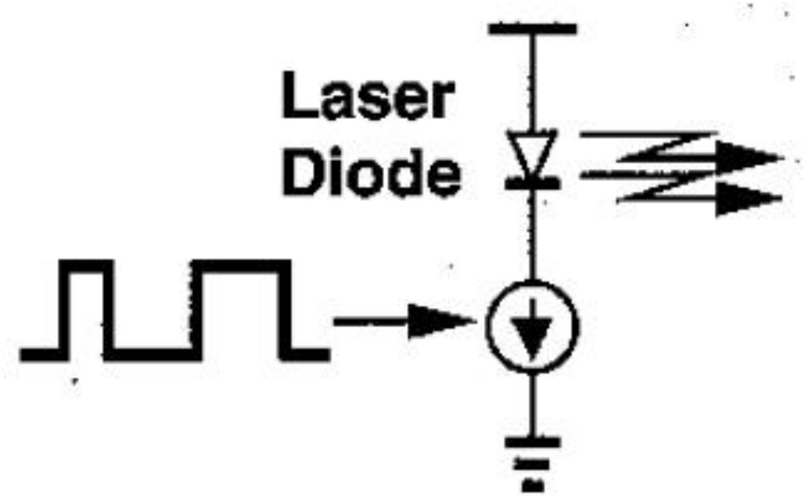
Control putere optica



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

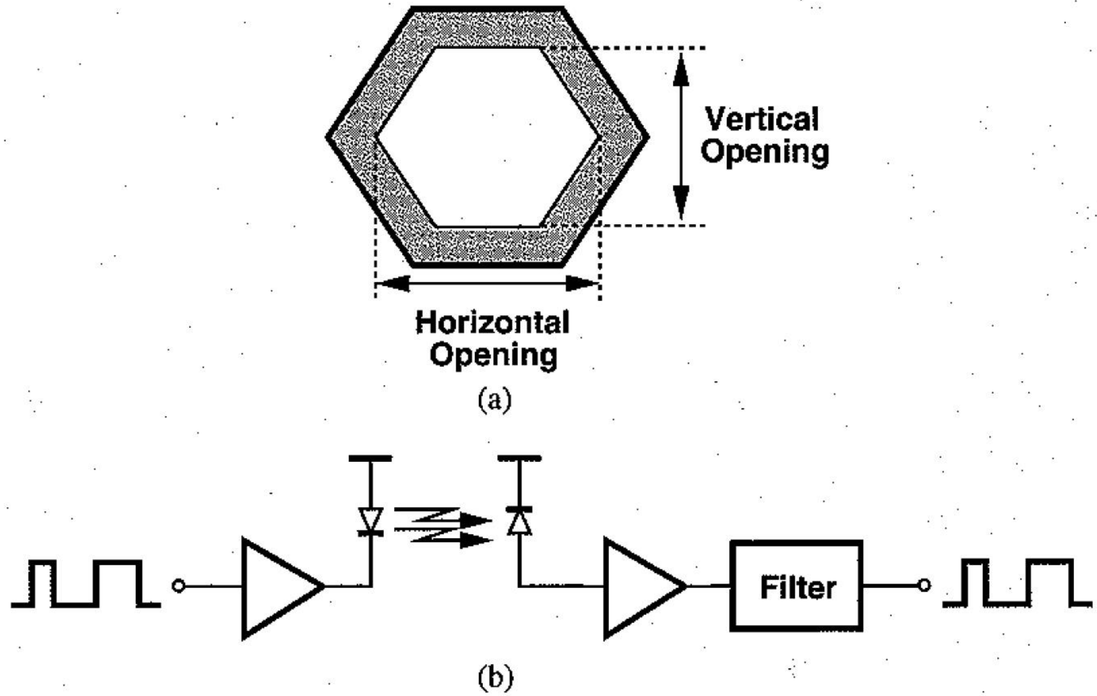


Dioda LASER

- 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

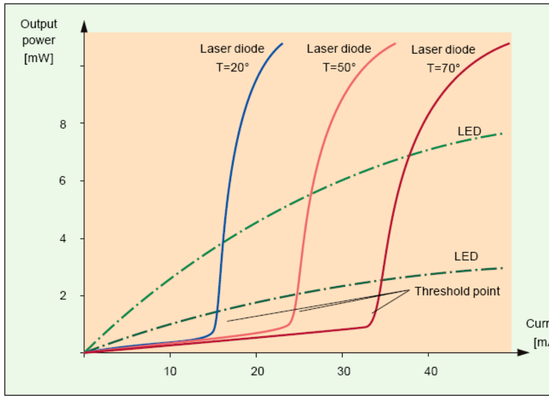
Caracteristici driver-e DL

- 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”



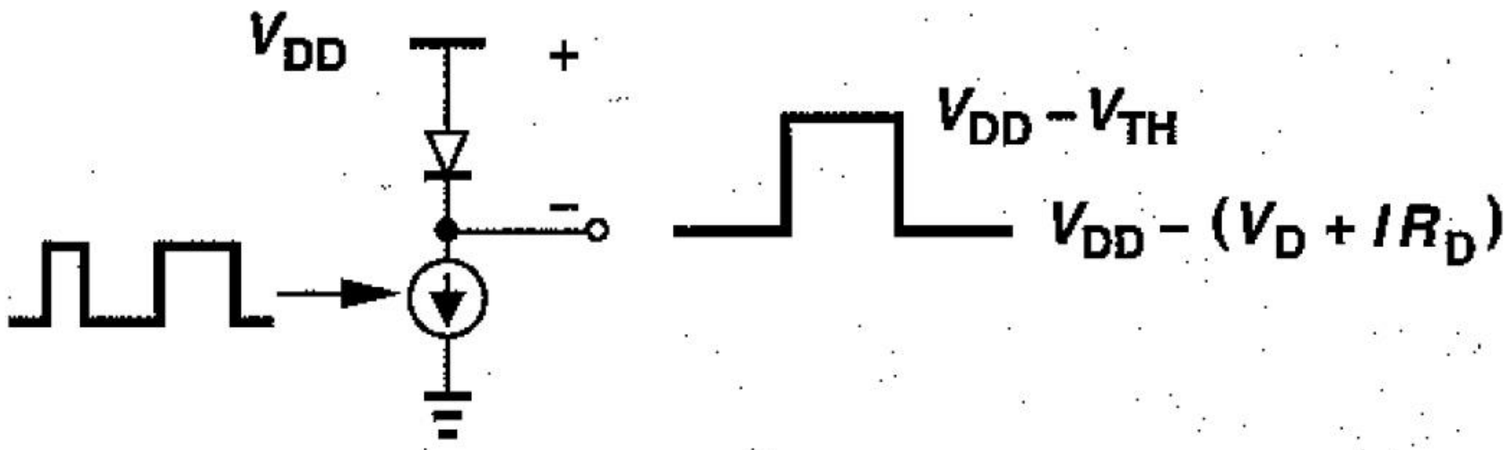
Caracteristici driver-e DL

- 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



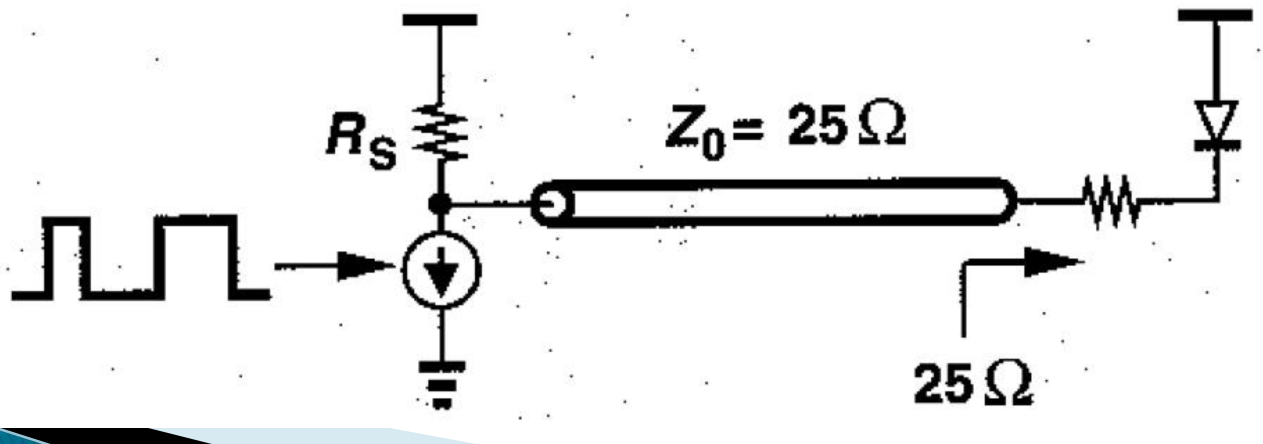
Caracteristici driver-e DL

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



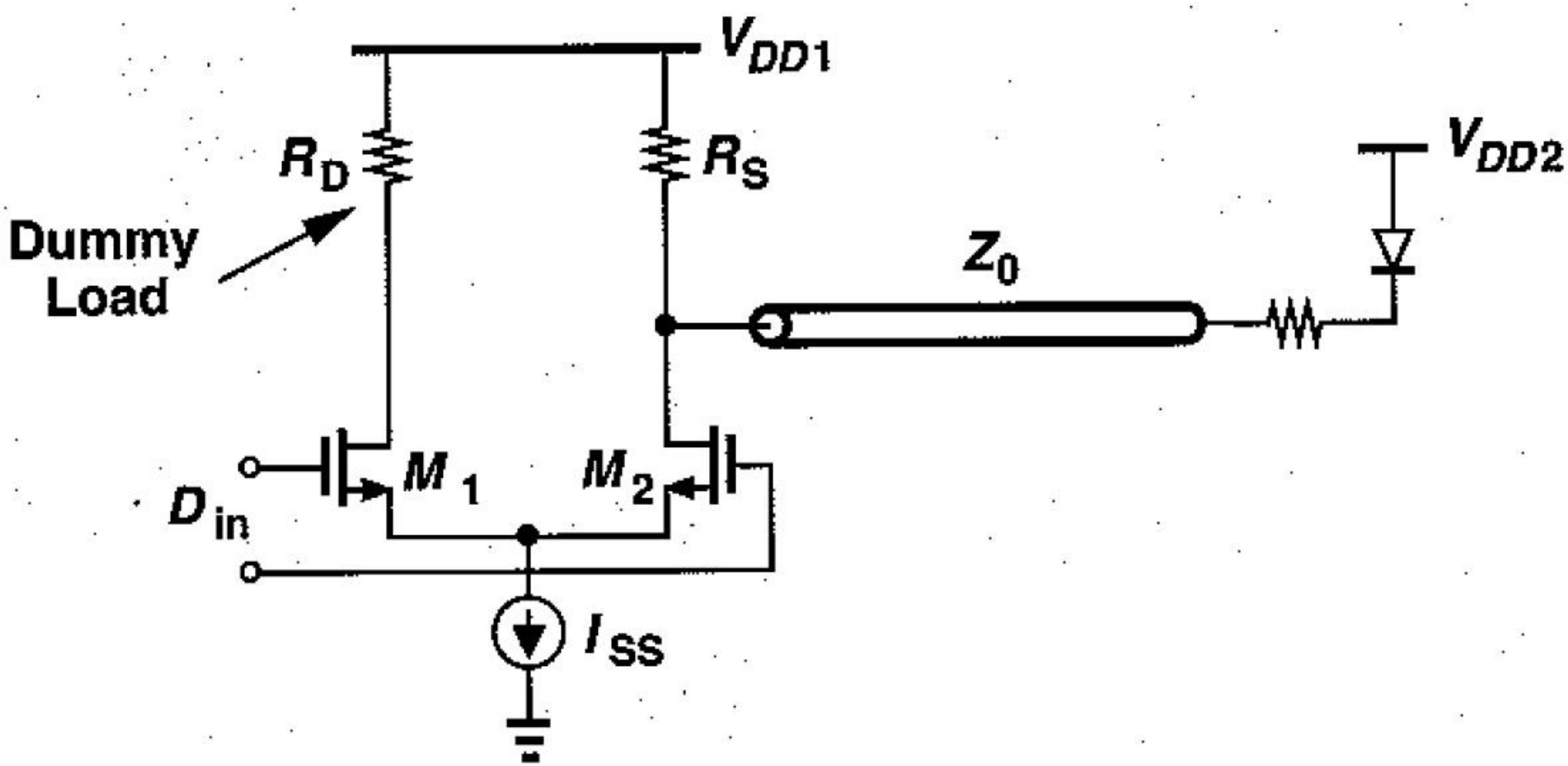
Caracteristici driver-e DL

- 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



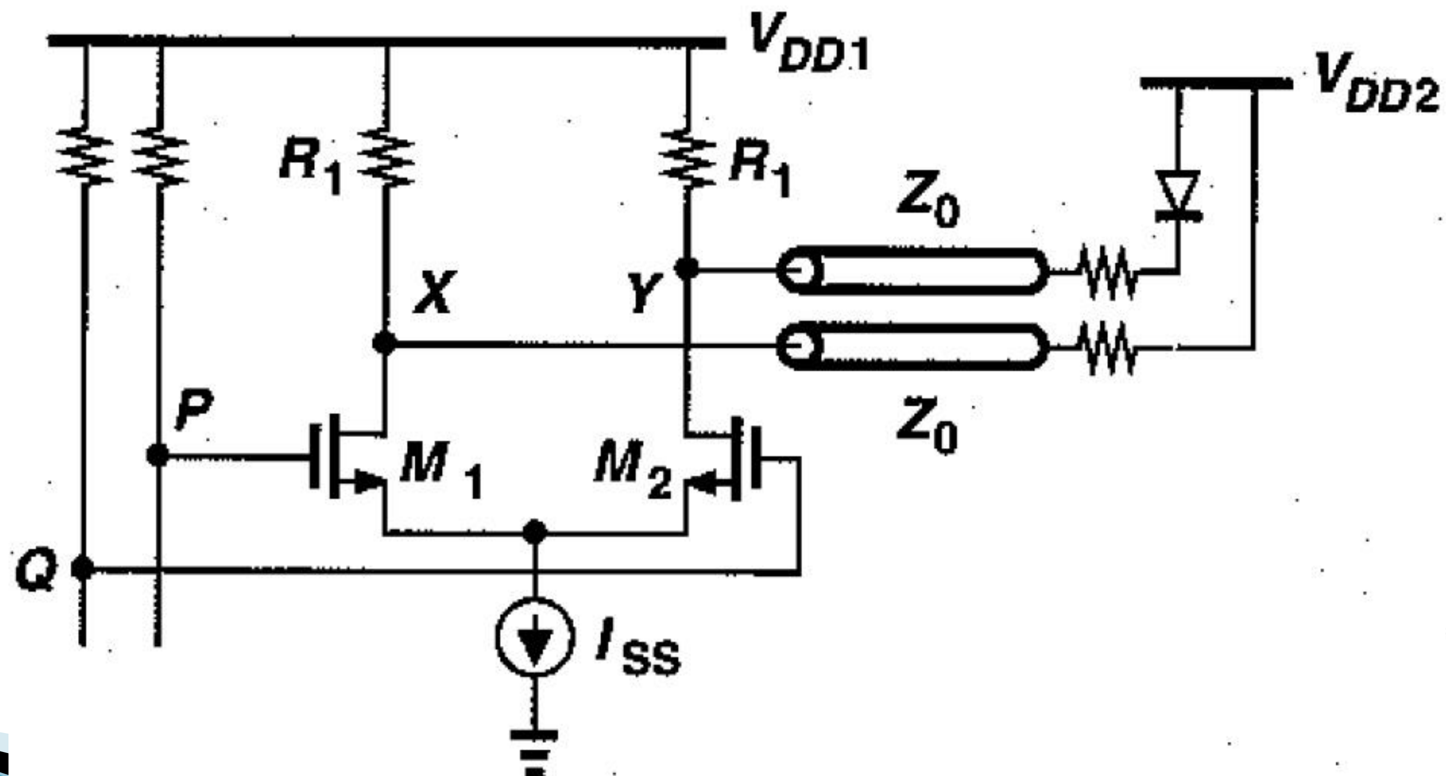
Principii de proiectare

- Tipic etajul de iesire se realizeaza diferential



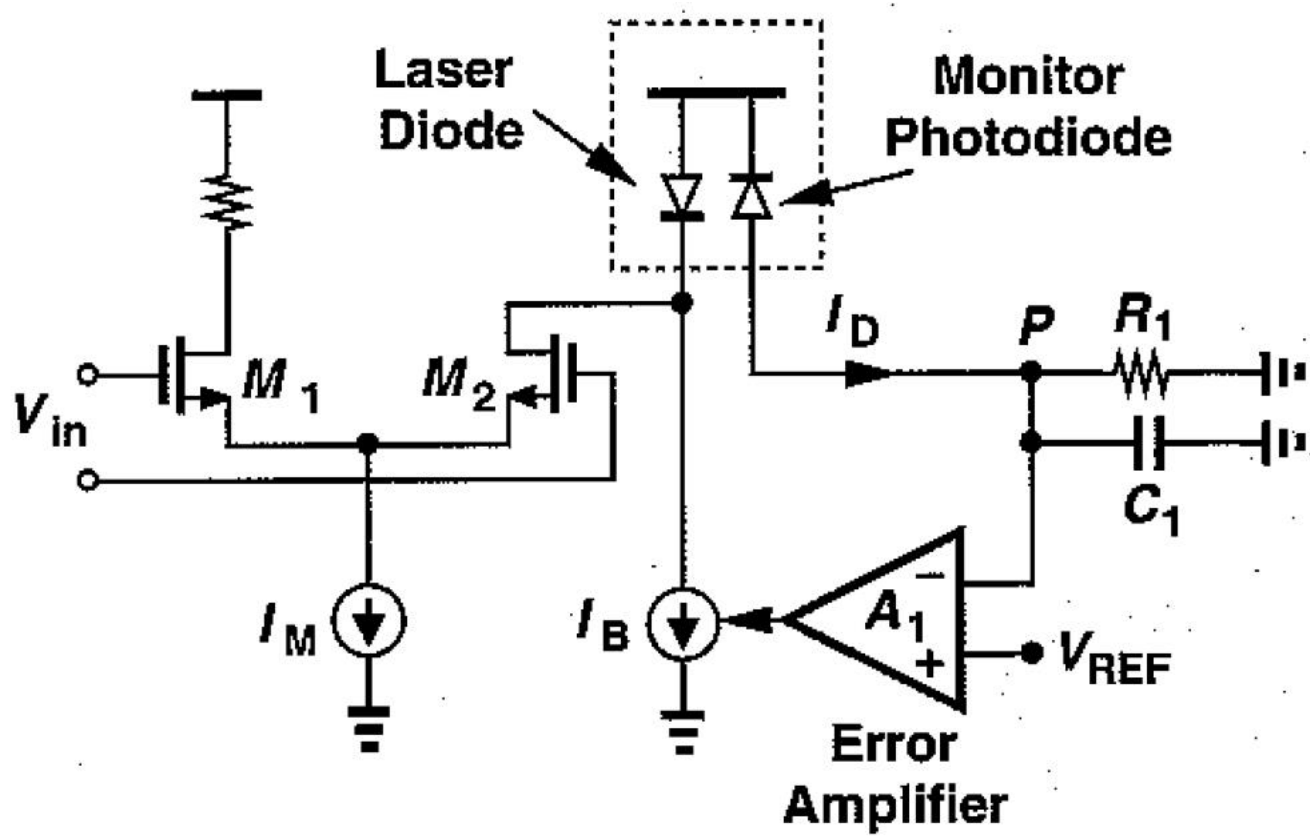
Principii de proiectare

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



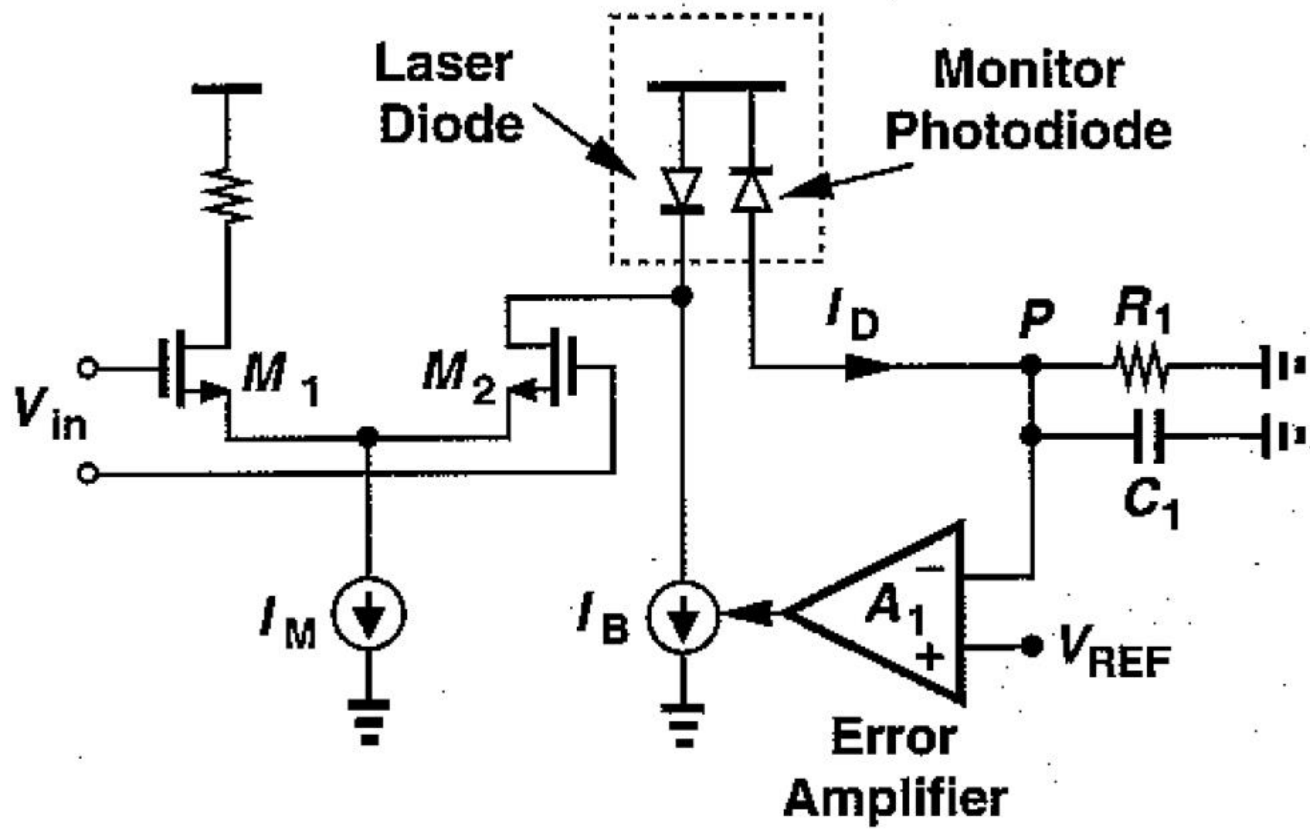
Controlul puterii in DL

- Necesar datorita variatiei curentului de "polarizare"



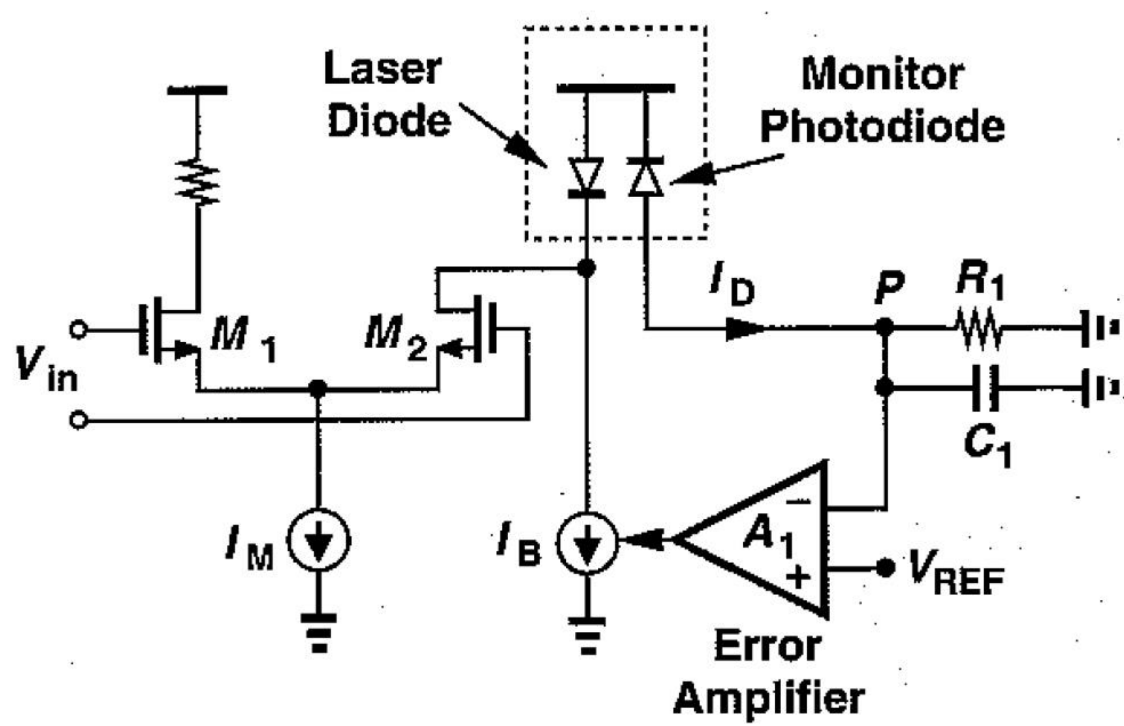
Controlul puterii in DL

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



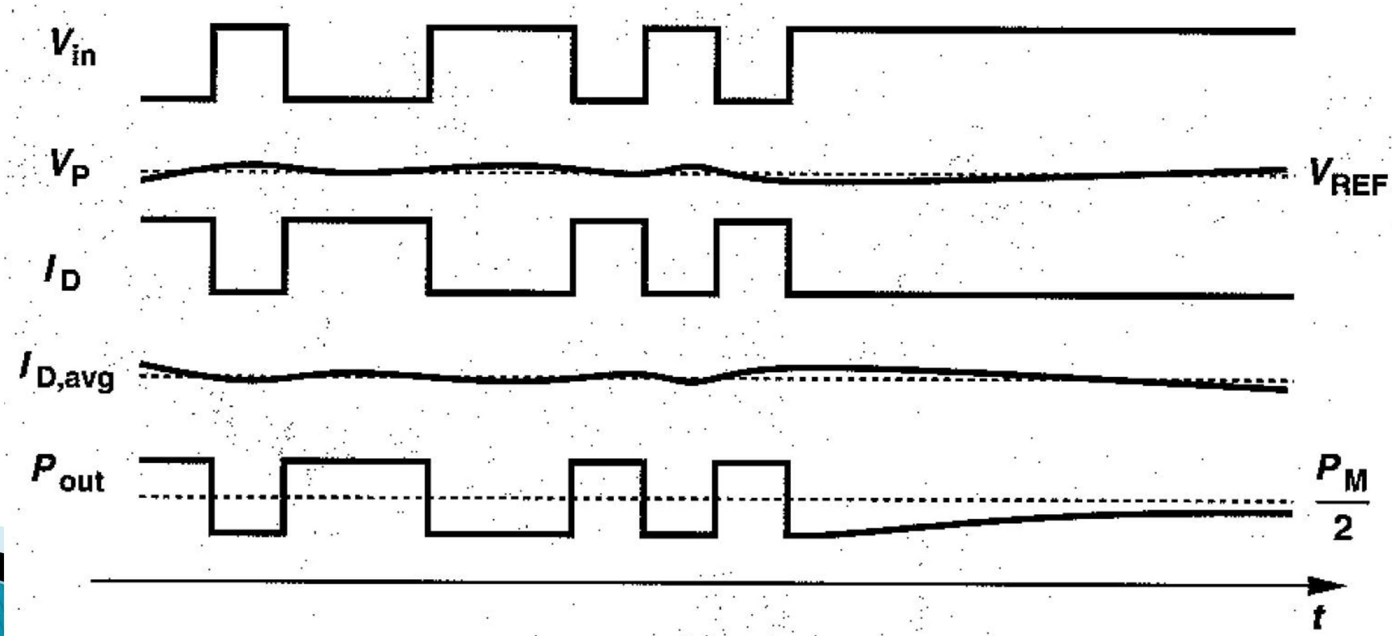
Controlul puterii in DL

- 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

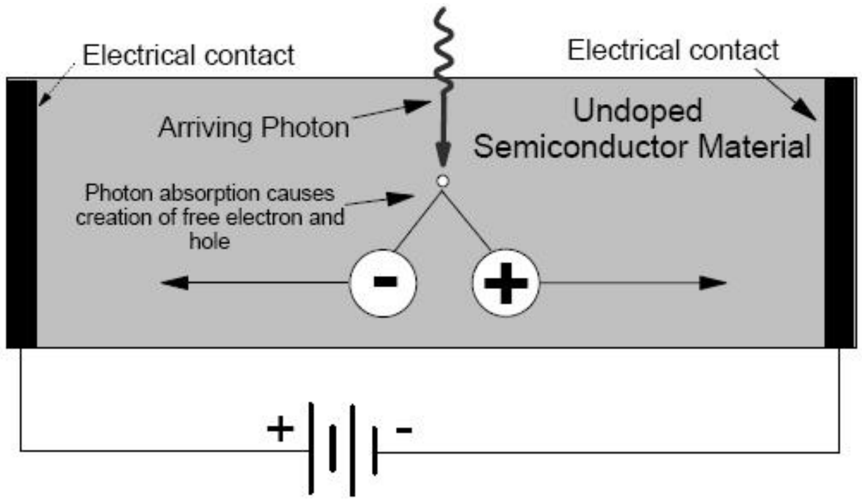
- **Lumina ca undă electromagnetică** (ecuaţiile lui Maxwell, ecuaţia undelor, parametrii de propagare)
- **Elemente de fotometrie şi radiometrie** (mărimi energetice/luminoase)
- **Fibra optică** (realizare, principiu de funcţionare, atenuare, dispersie, banda de frecvenţă)
- **Cabluri optice** (tehnologie, 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)

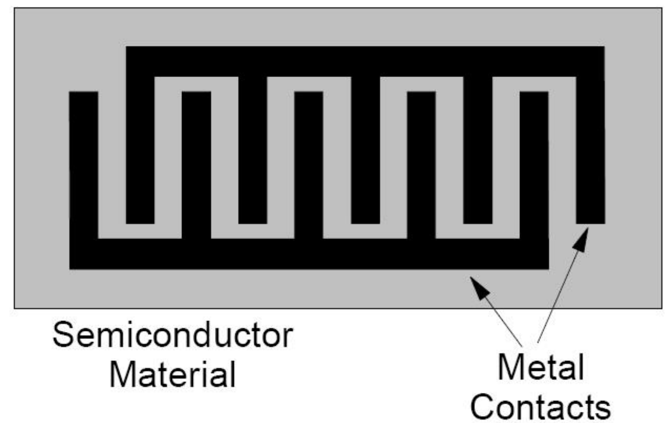
Detectori optici

- 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

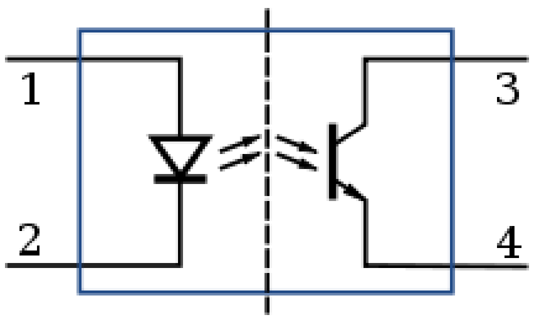


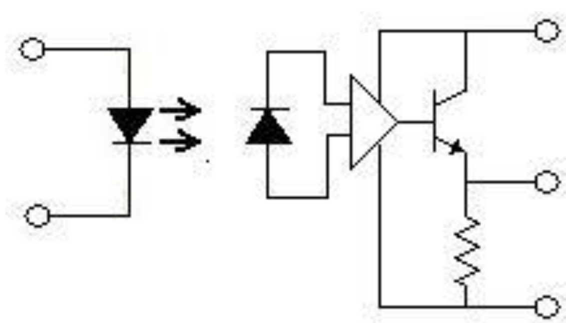


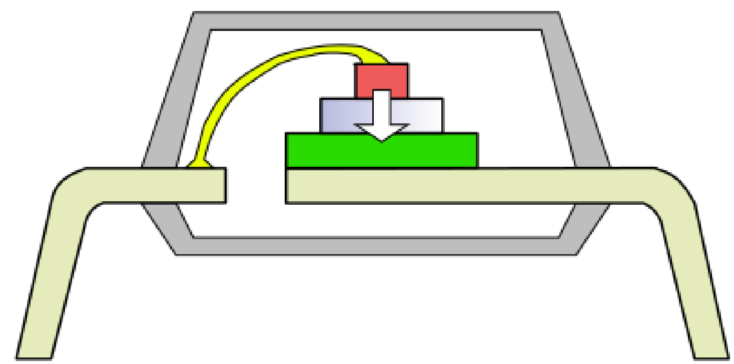
- Recent dispozitive Metal Semiconductor Metal (filtru interdigital) au inceput sa fie utilizate pentru usurinta de fabricare si integrare in aplicatii mai putin pretentioase

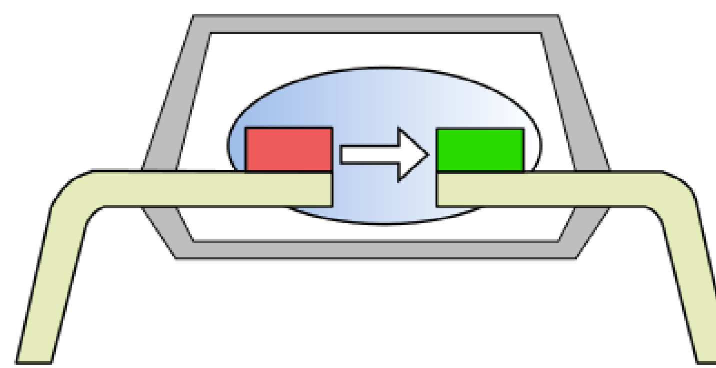
Optocuploare

- 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



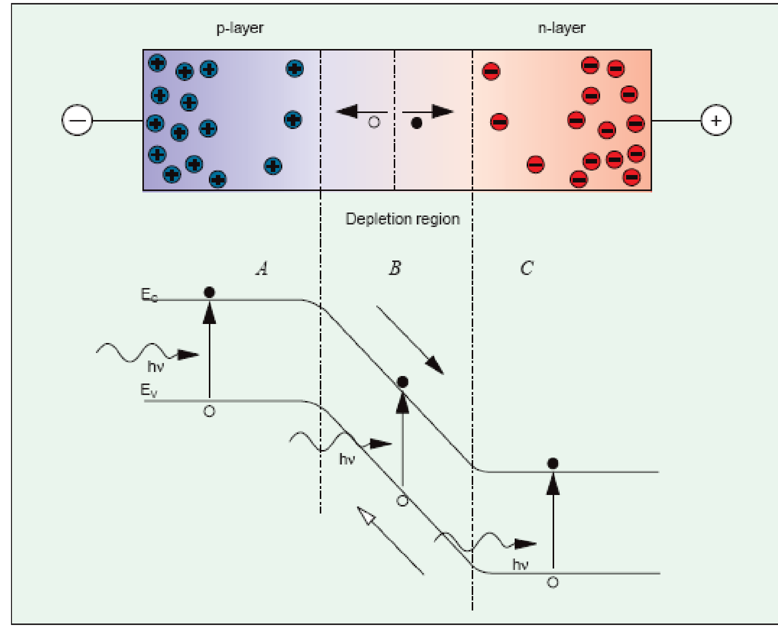


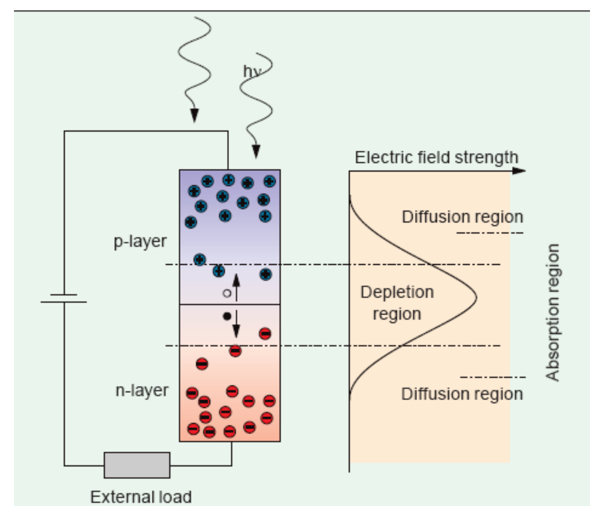




Fotodioda – Principiul de operare

- 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

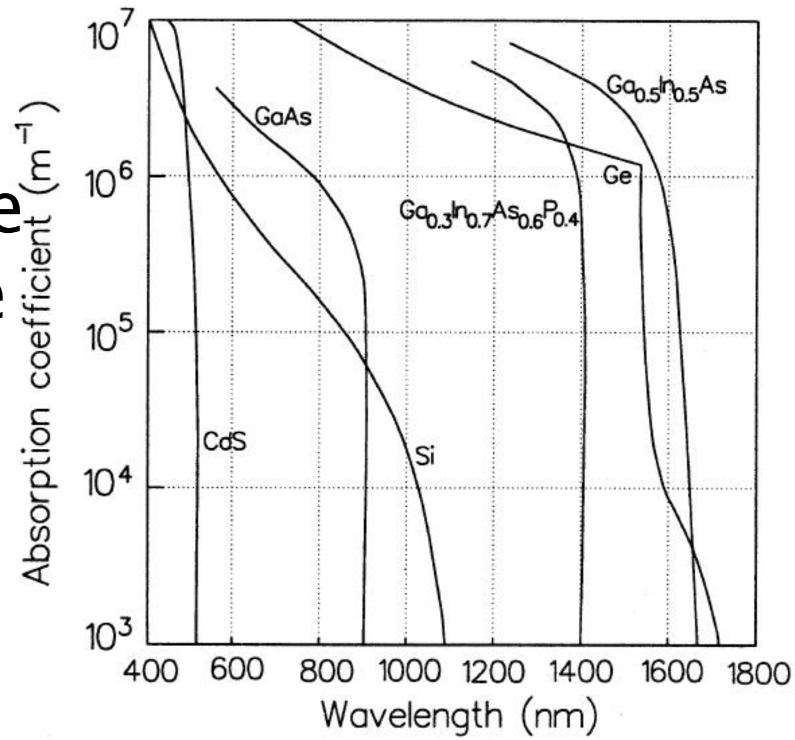
$$\lambda_{\max} = \frac{hc}{E_g}$$

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

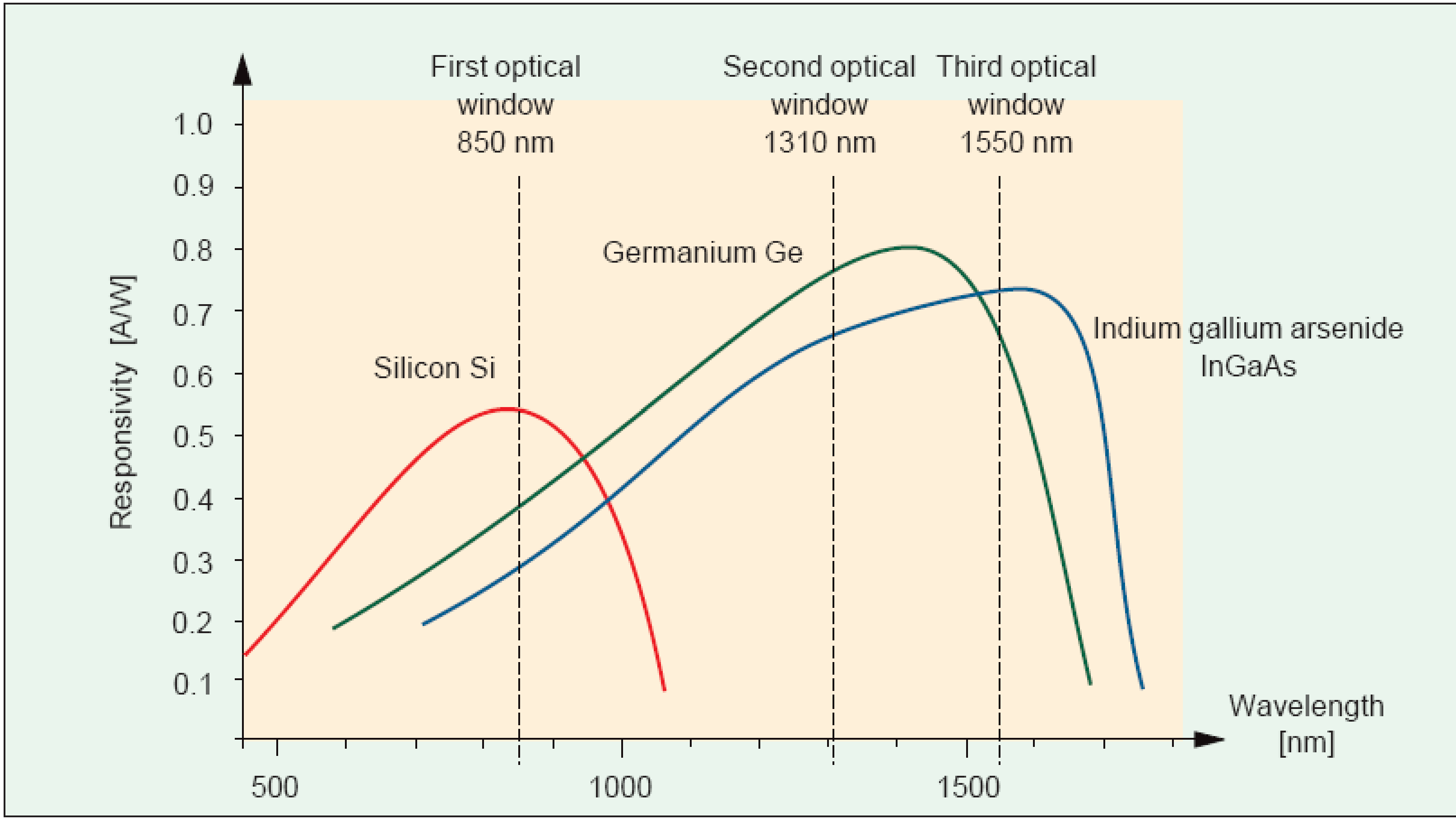
$$P(w) = P_i \cdot e^{-\alpha \cdot d} \cdot \left(1 - e^{-\alpha \cdot w}\right) \cdot \left(1 - R_f\right)$$

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

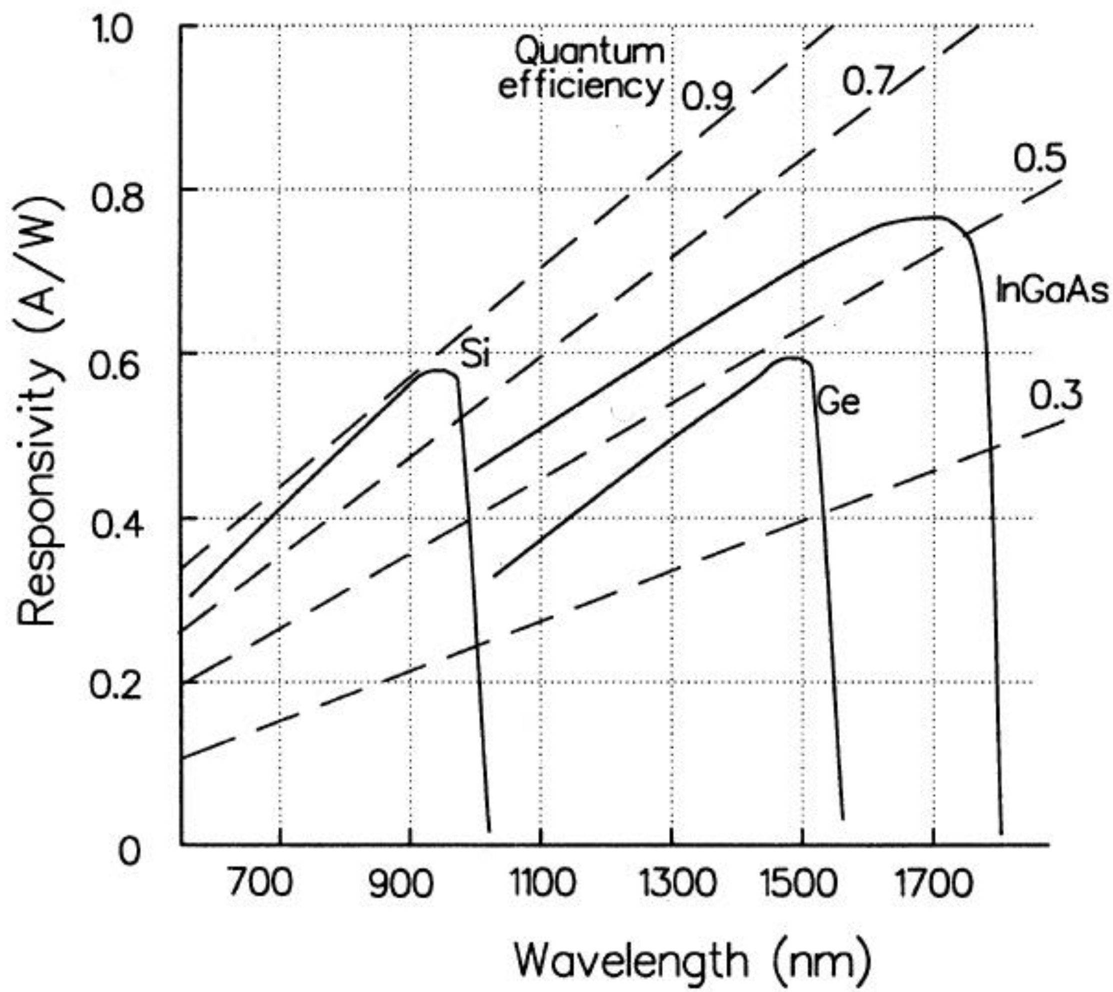
$$\eta = \frac{I/e}{P/h\nu}$$

- 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

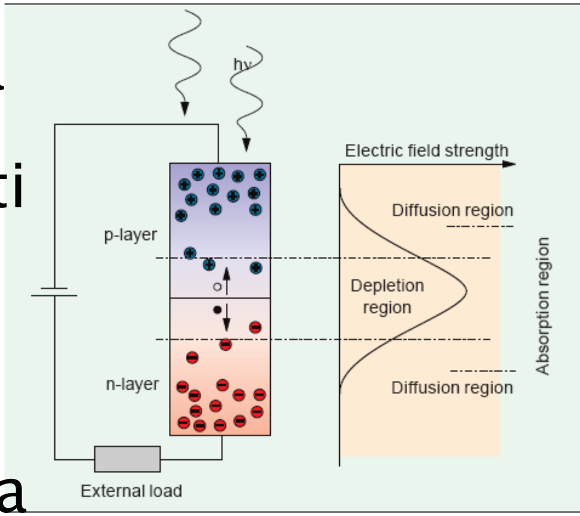
- Curentul invers al jonctiunii p-n, datorat agitatiei termice, prezent in absenta iluminarii
- Constituie o importanta sursa de zgomot (limiteaza aplicatiile Ge)

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

  - 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)

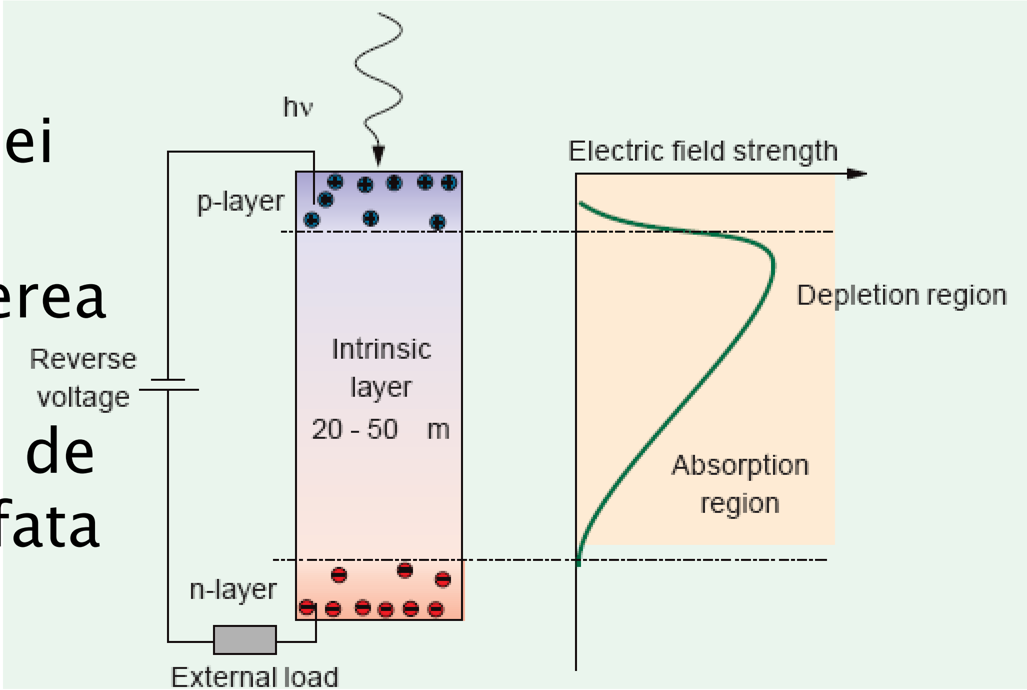


- Puterea optica absorbita in interiorul acestei zone e in consecinta redusa
- Purtatorii generati inafara zonei de golire ajung eventual in zona golita si vor fi accelerati spre terminale, dar viteza fenomenului este prea redusa pentru aplicatii in comunicatii

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

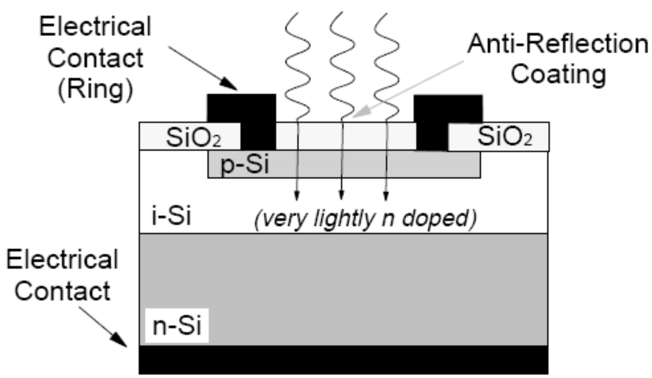
Fotodioda PIN

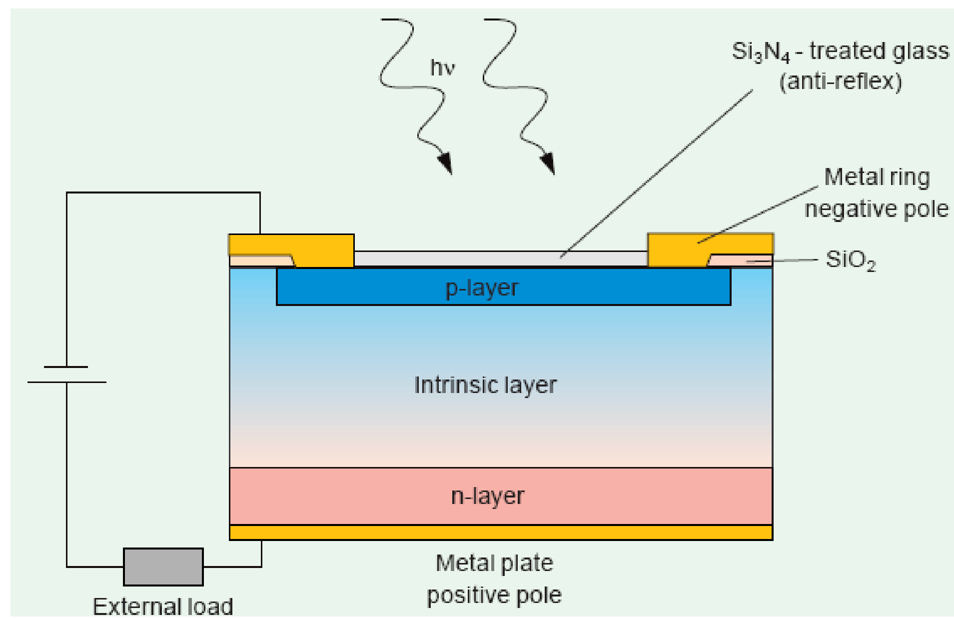
- Solutia consta in introducerea unui strat foarte slab dopat (intrinsec) intre cele doua zone ale diodei
  - creste volumul de absorbtie deci creste sensibilitatea fotodiodei
  - capacitatea jonctiunii scade ducand la cresterea vitezei
  - este favorizat curentul de conductie (mai rapid) fata de cel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



Structura fotodiodei PIN

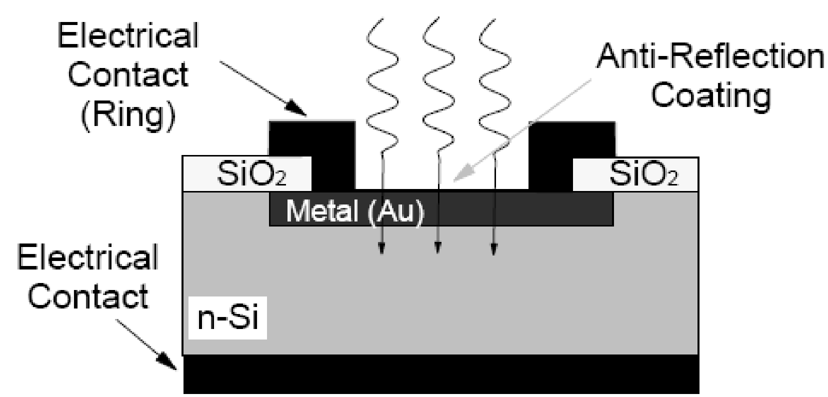
- tipic, adancimea stratului intrinsec este de 20–50μm
- cresterea suplimentara a adancimii ar duce la cresterea timpului de tranzit
  - w=20μm -> $T_{tr} \cong 0.2ns$





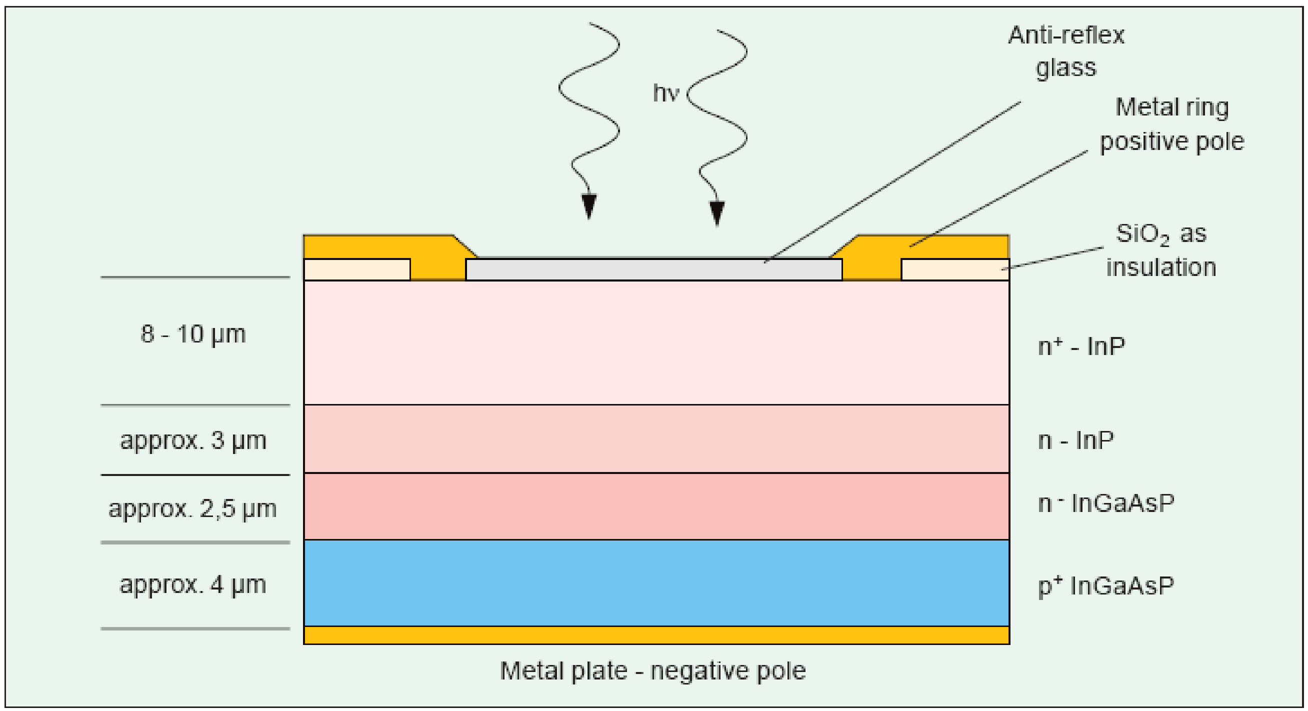
Structura fotodiodelor Schottky

- 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



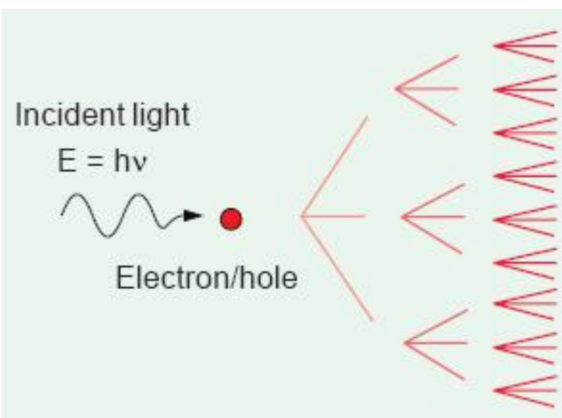
Fotodioda PIN pentru lungimi de unda crescute (1550nm)

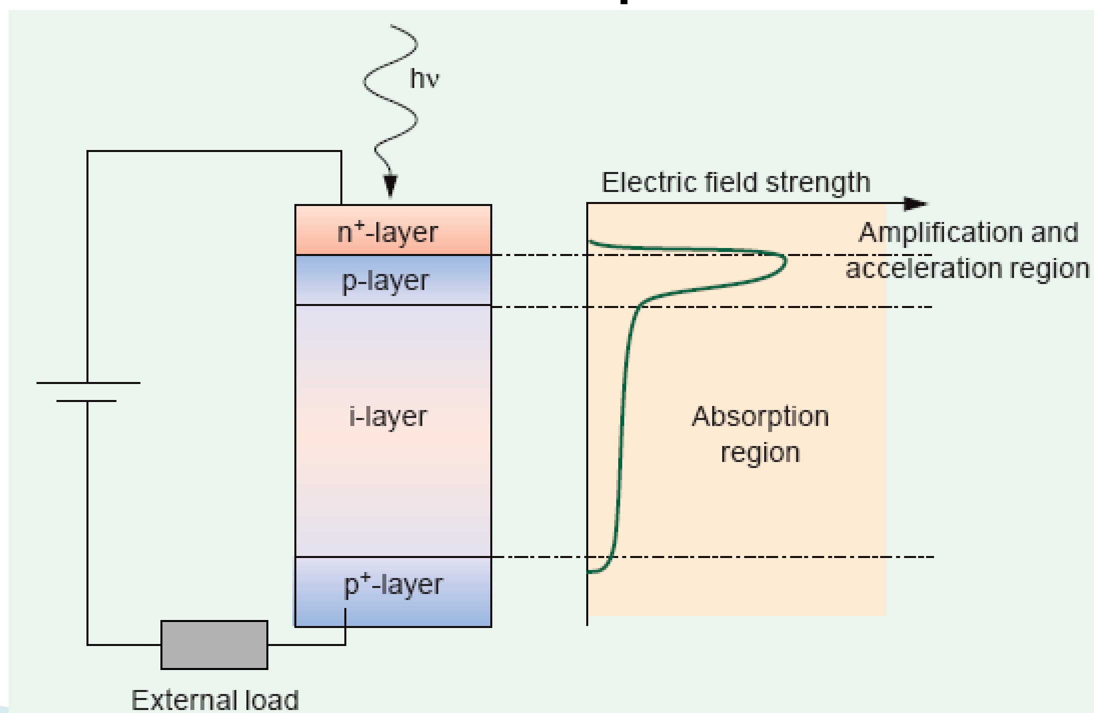
- se utilizeaza tipic
  - InGaAsP pe substrat InP
  - GaAlAsSb pe substrat GaSb



Fotodioda PIN cu multiplicare in avalansa

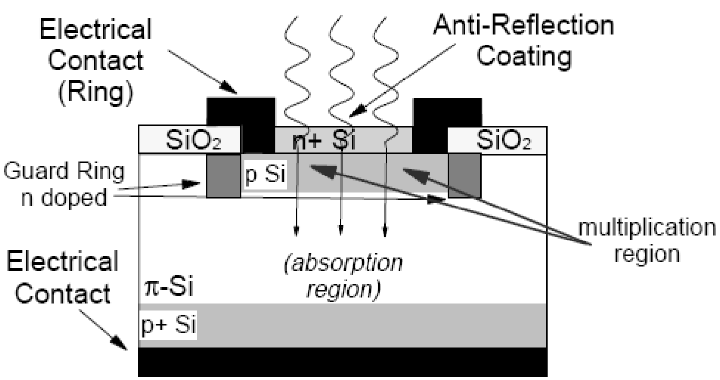
- daca viteza purtatorilor este suficient de mare genereaza noi perechi electron/gol prin ionizare de impact
- amplificarea are loc in acelasi timp cu detectia

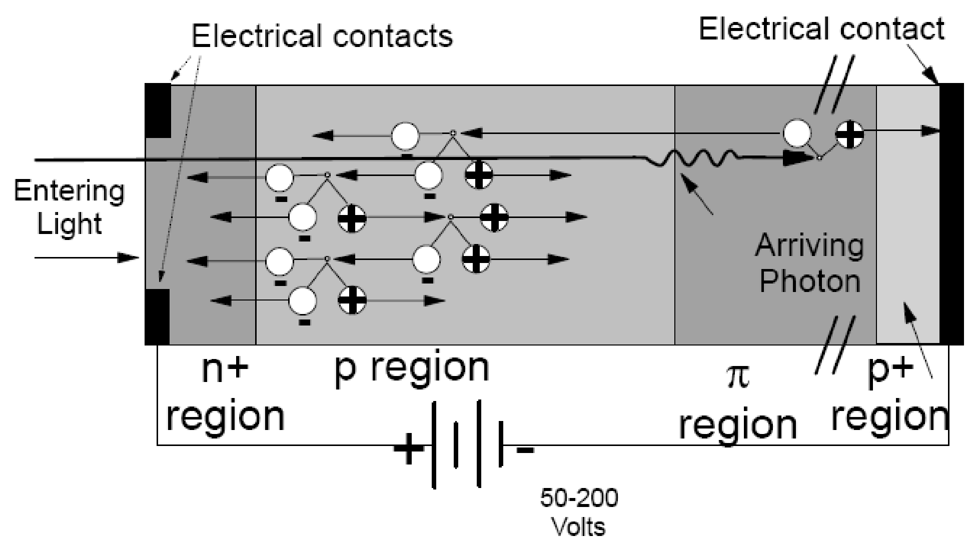




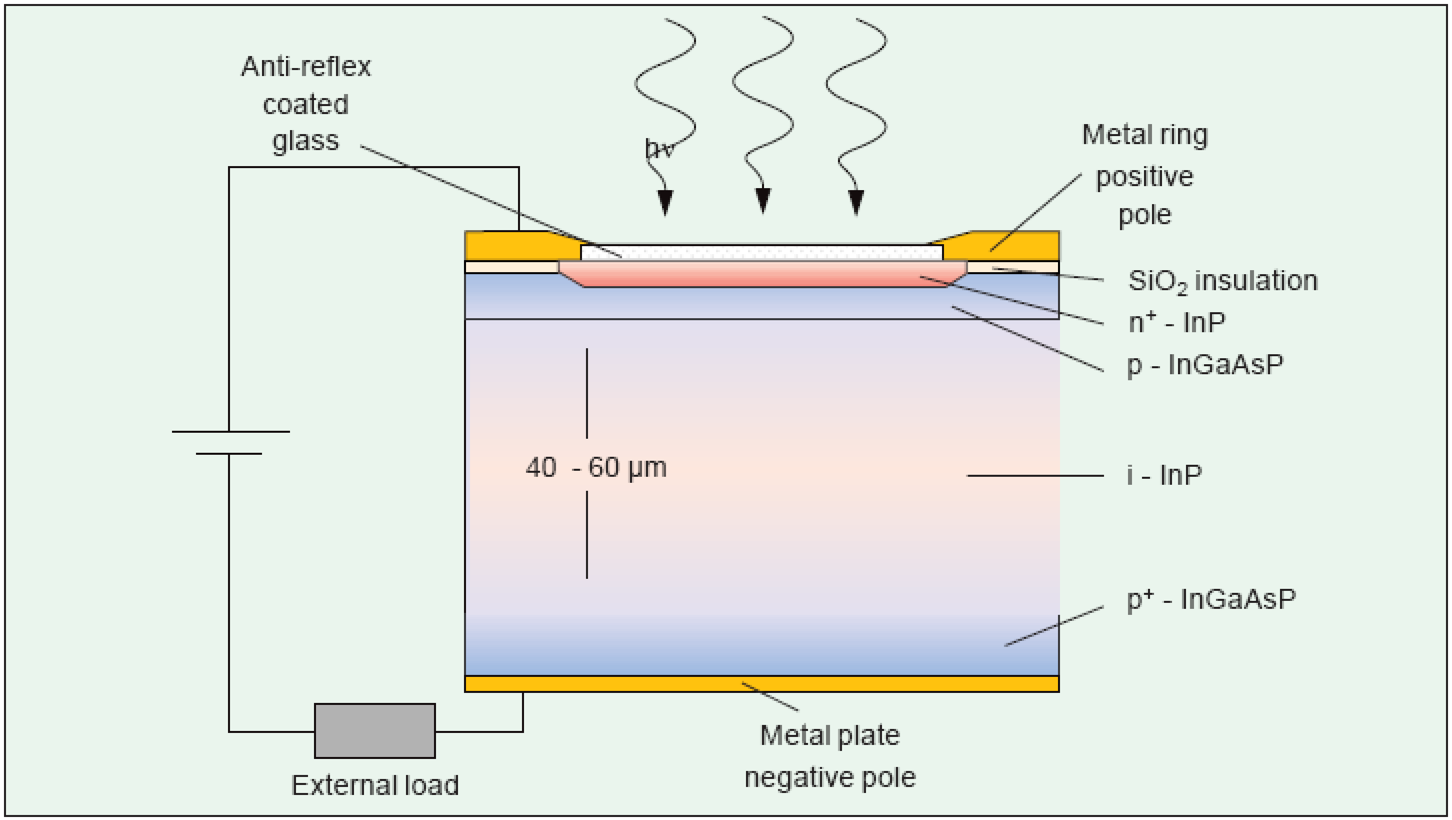
Functionarea fotodiodei cu multiplicare in avalansa

- 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





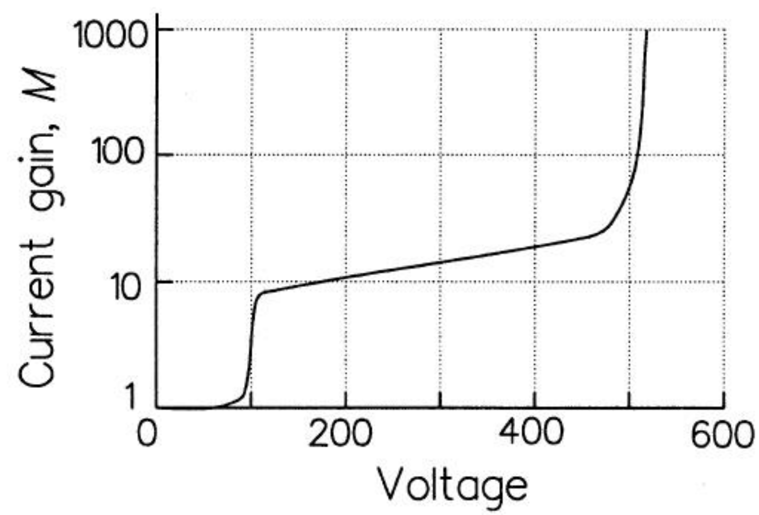
Structura fotodiodei cu multiplicare in avalansa



Caracteristicile fotodiodei cu multiplicare in avalansa

- factorul de multiplicare caracterizeaza amplificarea fotocurentului generat

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



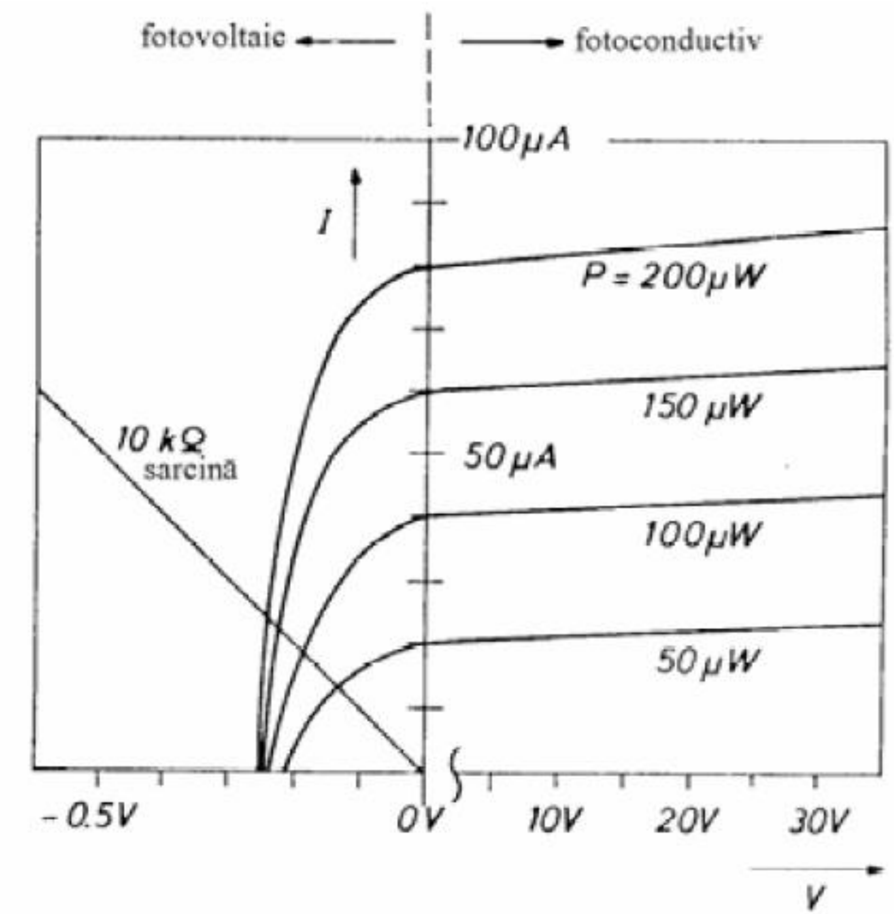
- Responzivitatea

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

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

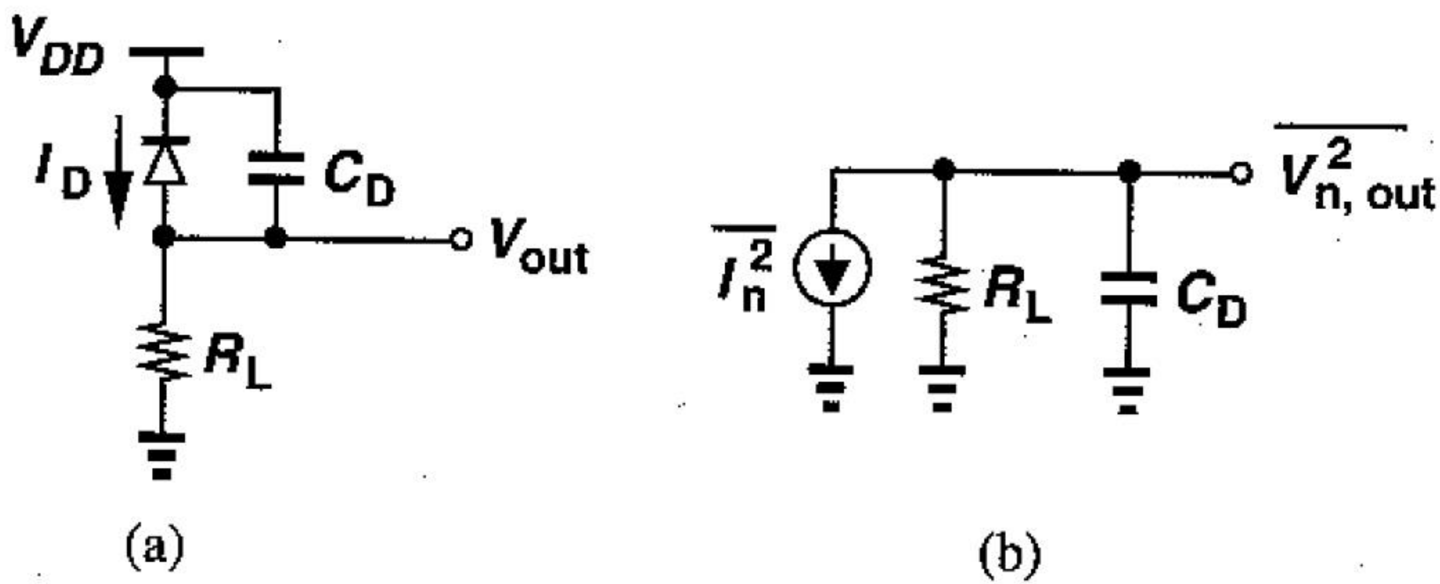


Amplificatoare transimpedanta

- 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)

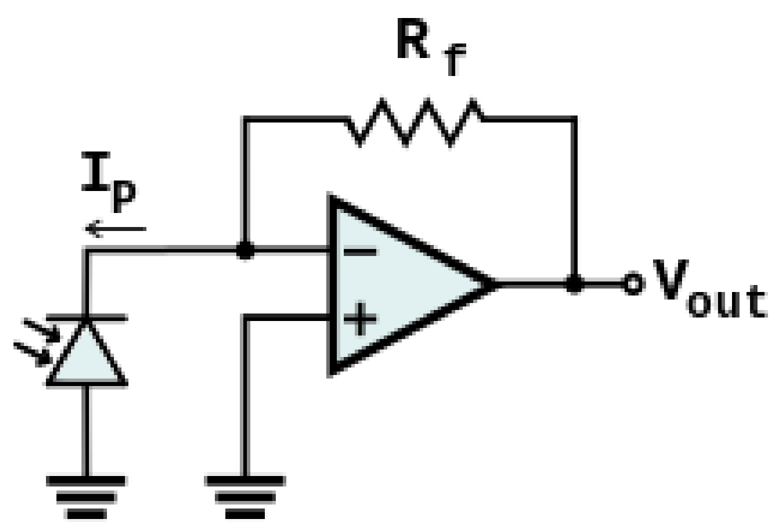
Amplificatoare transimpedanta

- Cel mai simplu amplificator transimpedanta este un rezistor

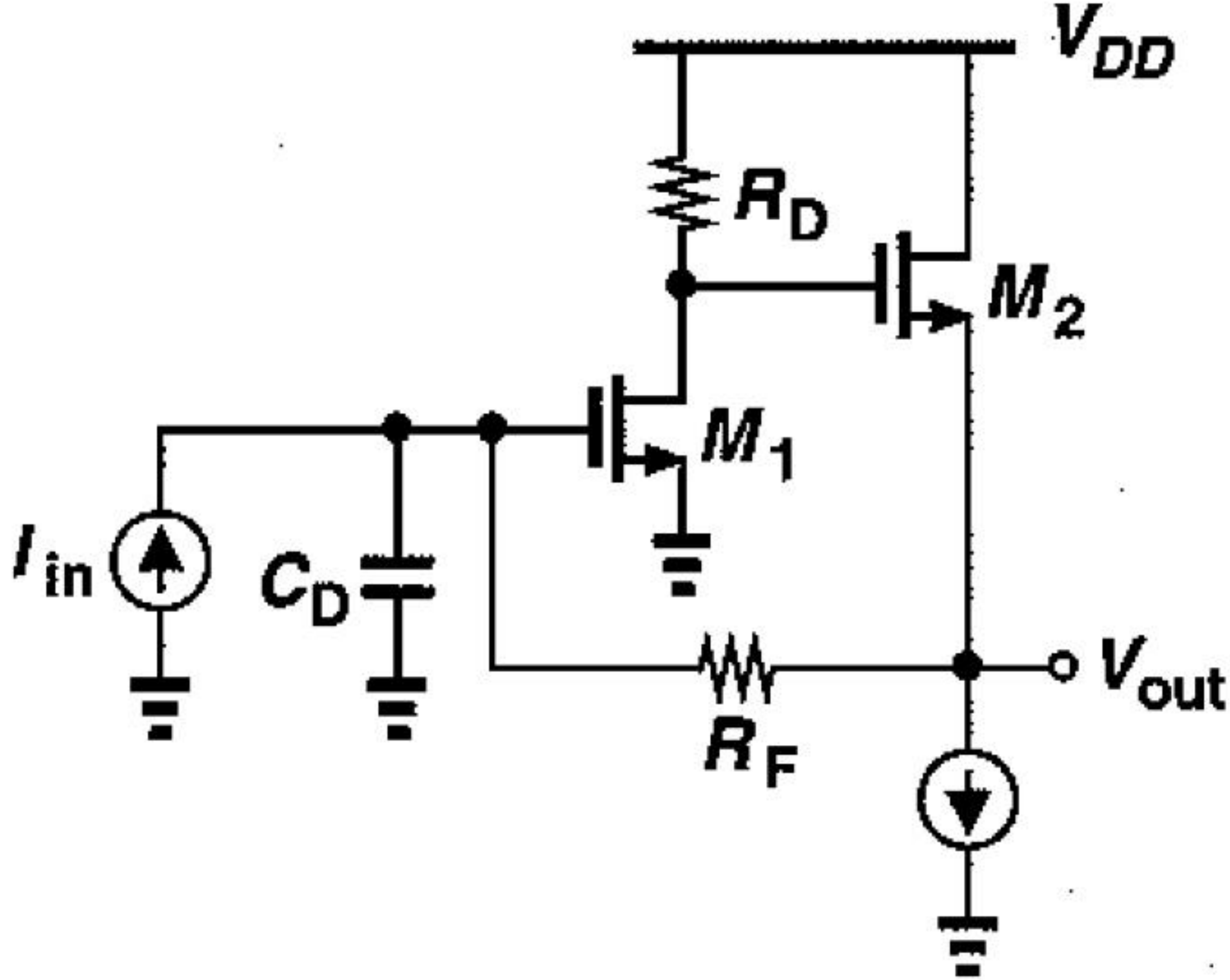


Amplificatoare transimpedanta

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



Amplificatoare transimpedanta



Zgomotul traductorilor electro-optici

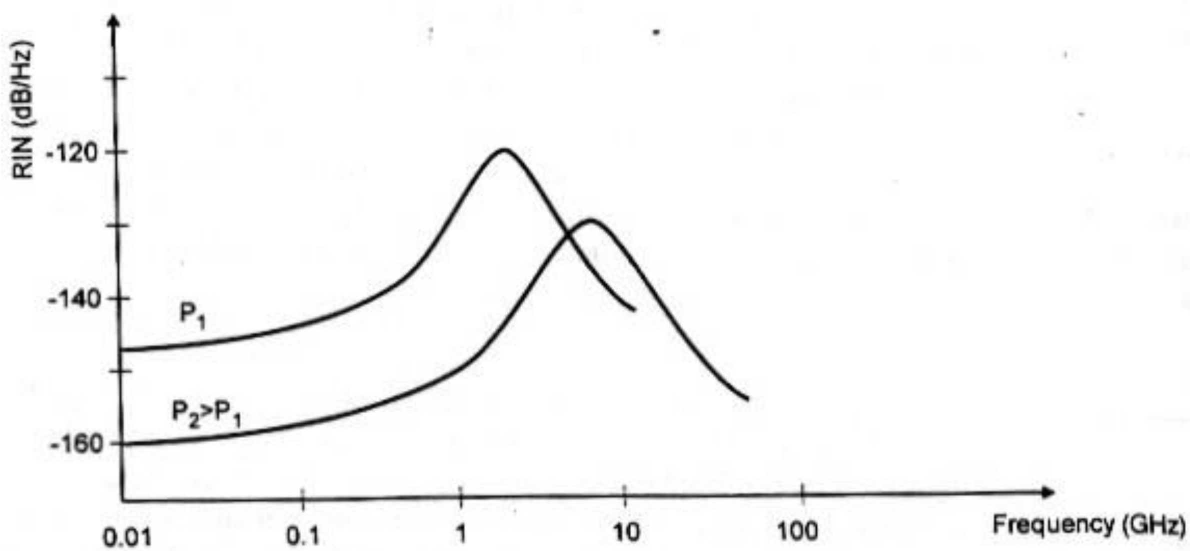
Zgomotul emitatorilor optici

- 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

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

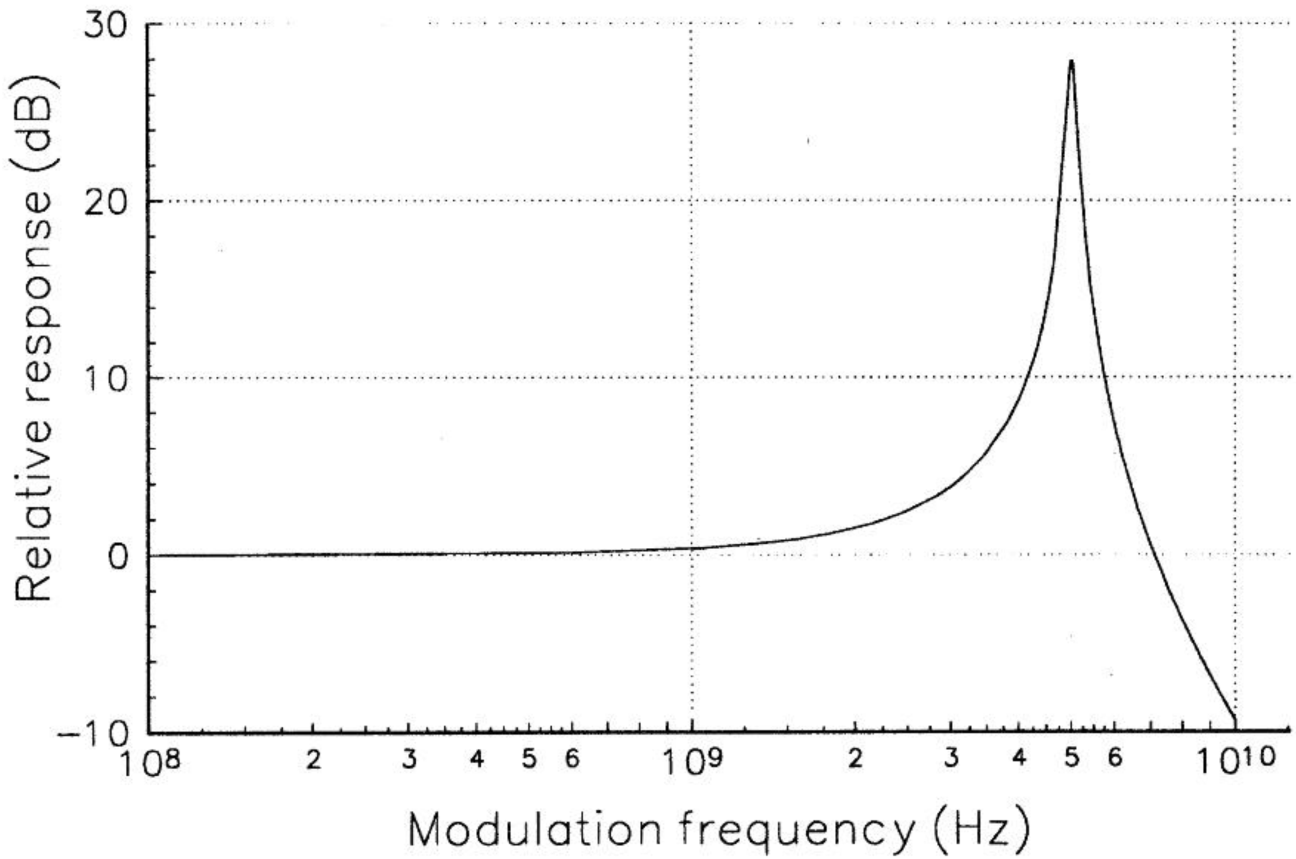
RIN

- 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

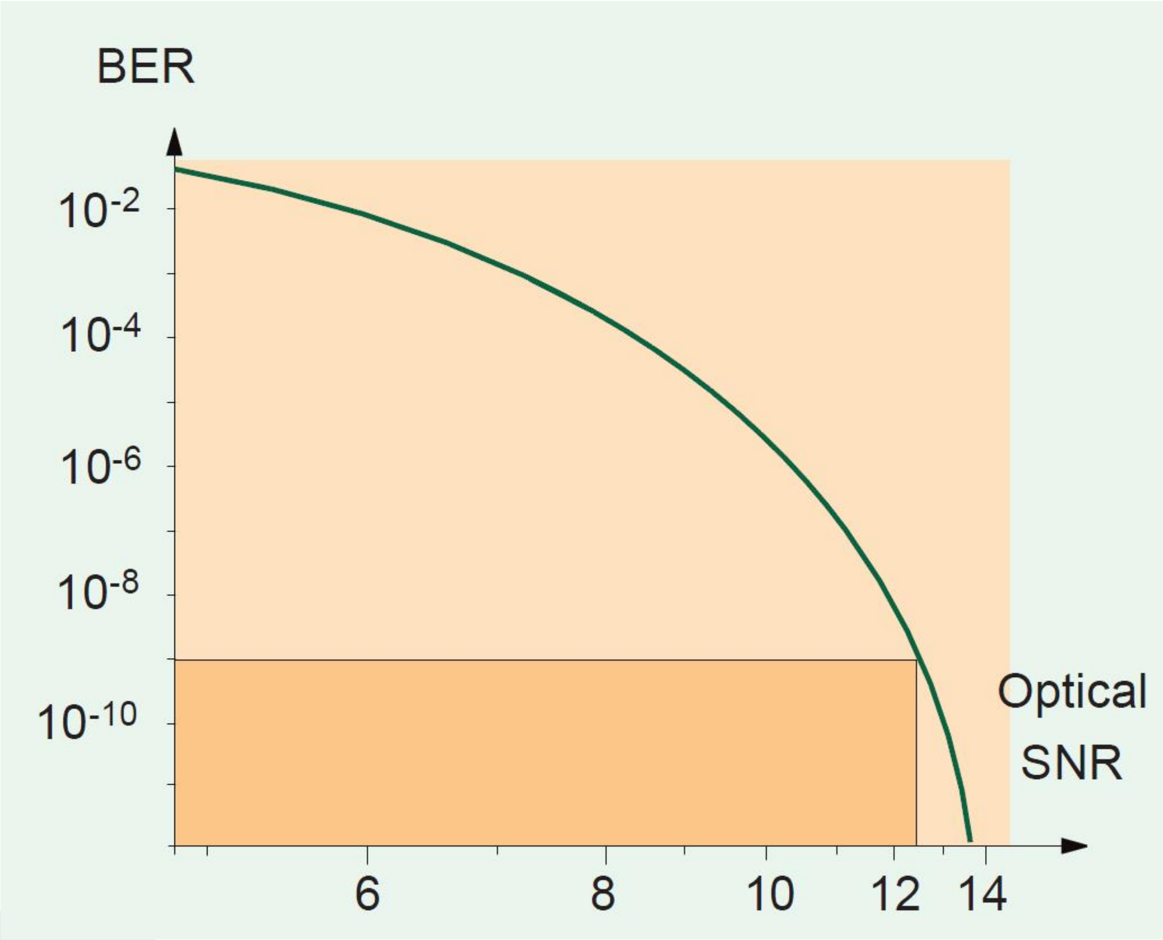
$$\left\langle i_n^2 \right\rangle = 2 \cdot e \cdot I \cdot BW_{PD} = 2 \cdot e \cdot \left(I_S + I_{dark} \right) \cdot BW_{PD}$$

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

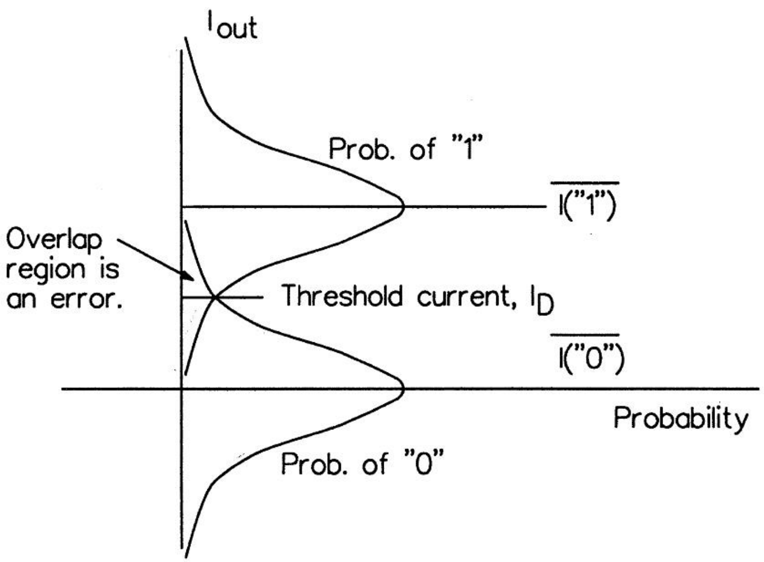
$$NEP[W / \sqrt{Hz}] == \frac{1}{r} \cdot \sqrt{2 \cdot e \cdot I_{dark}}$$

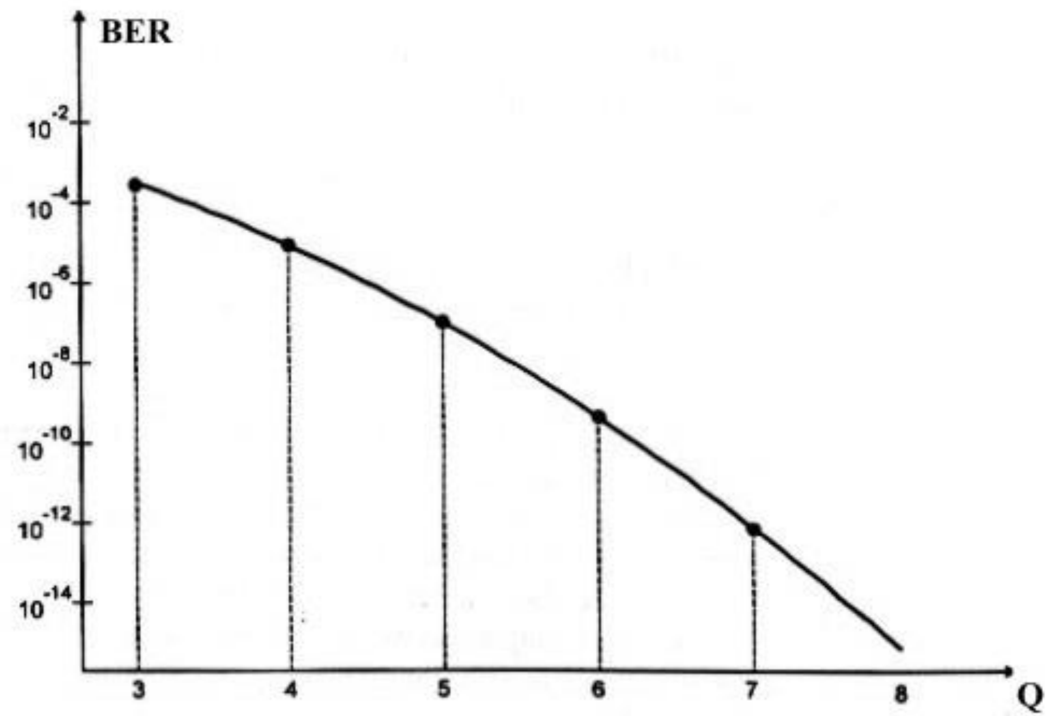
BER

- Bit Error Rate



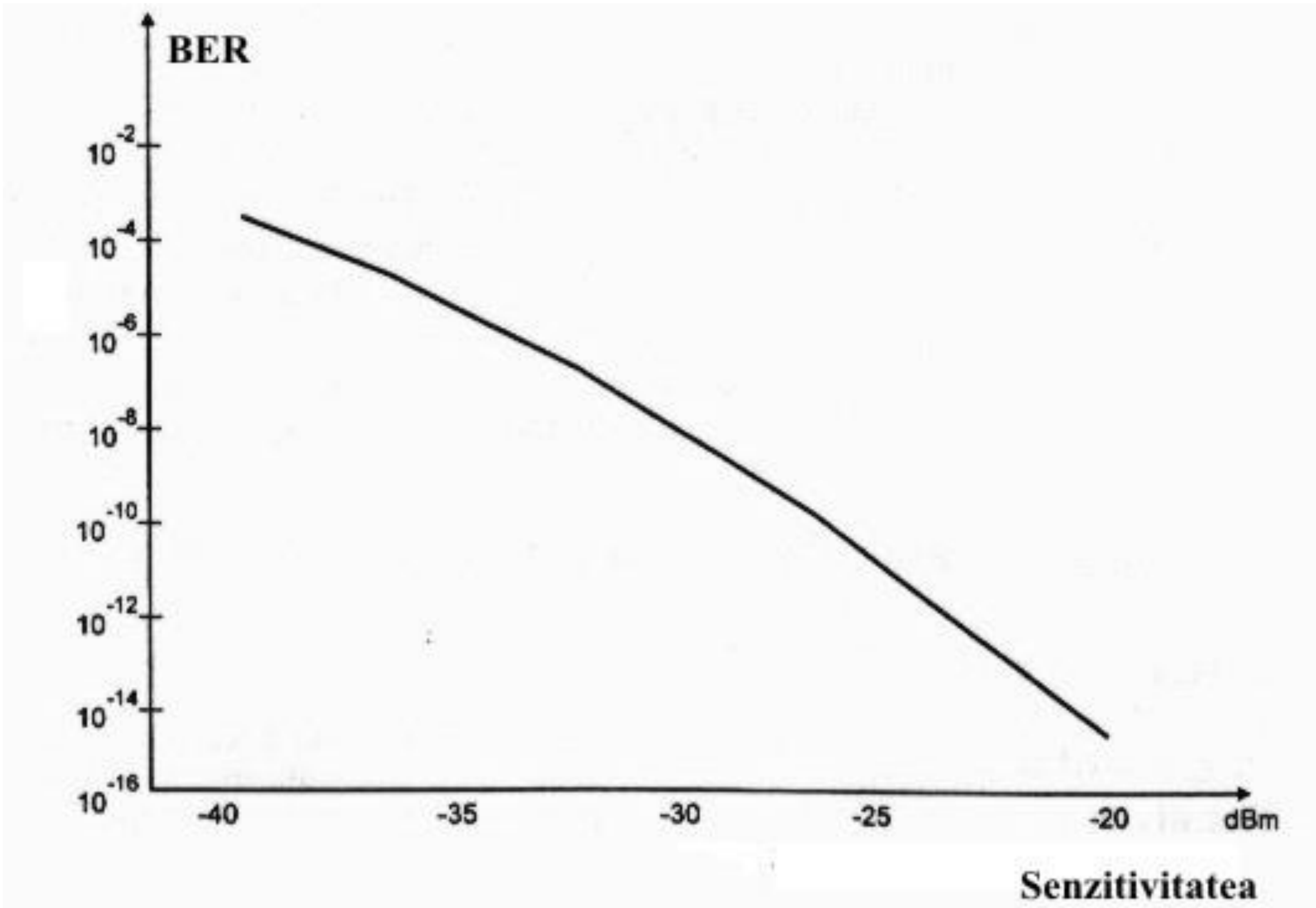
Probabilitate de eroare





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

Senzitivitatea unei diode



Utilizare celule solare

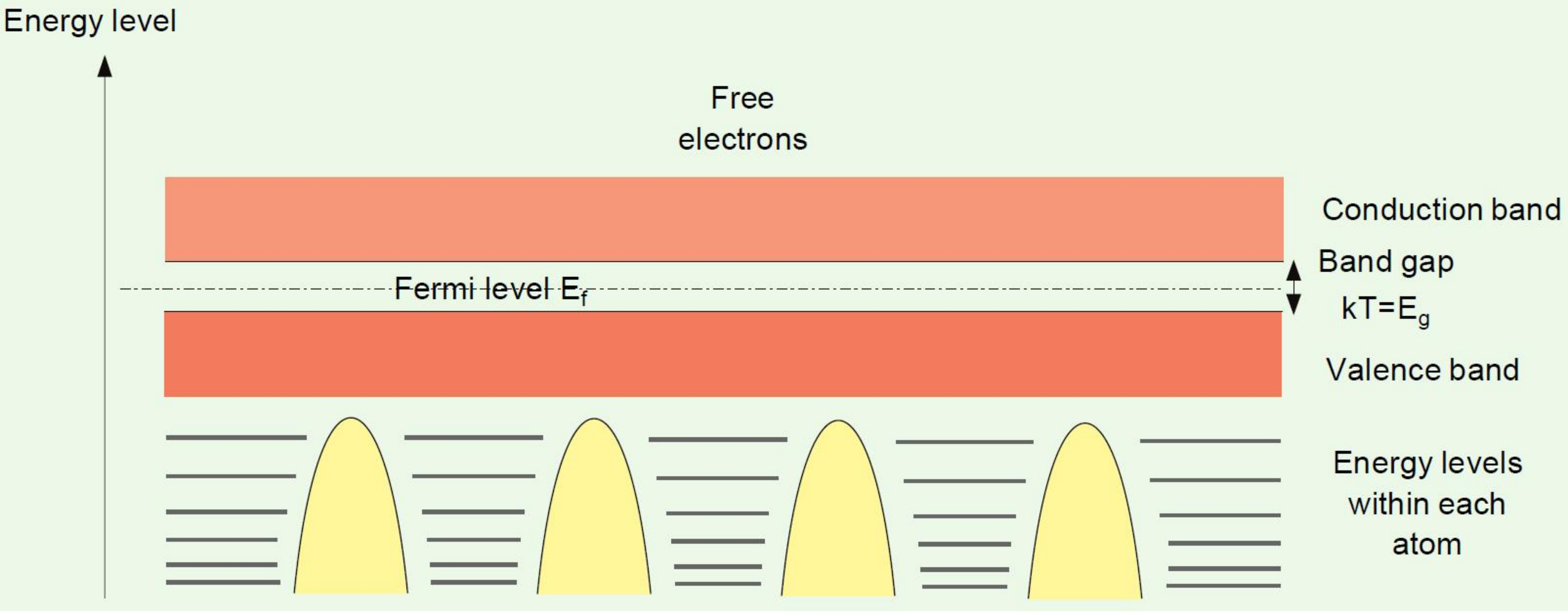
Capitolul 10

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)

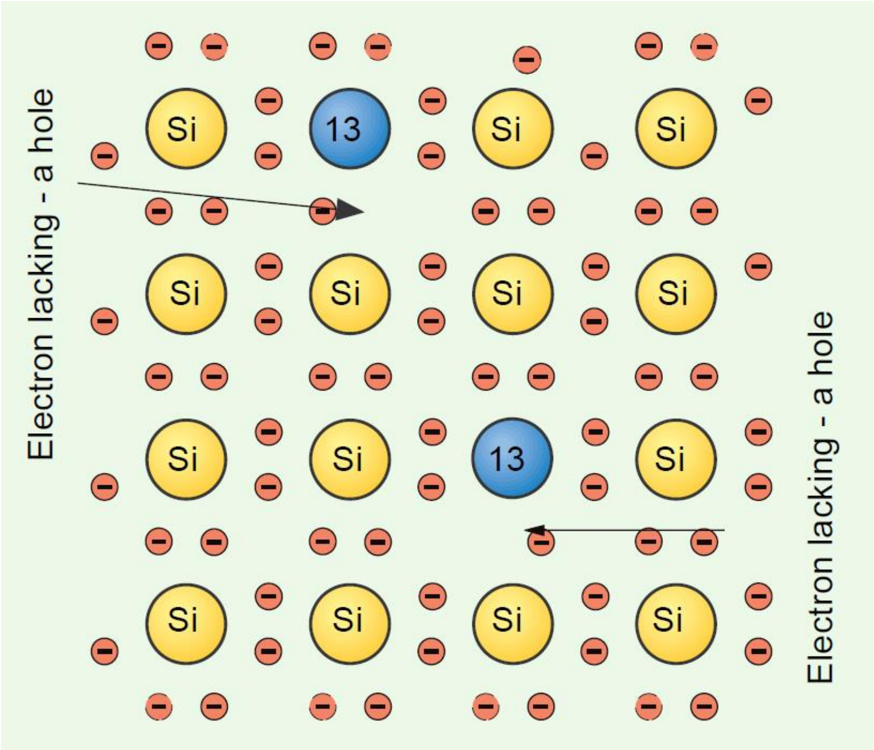
Efect fotovoltaic

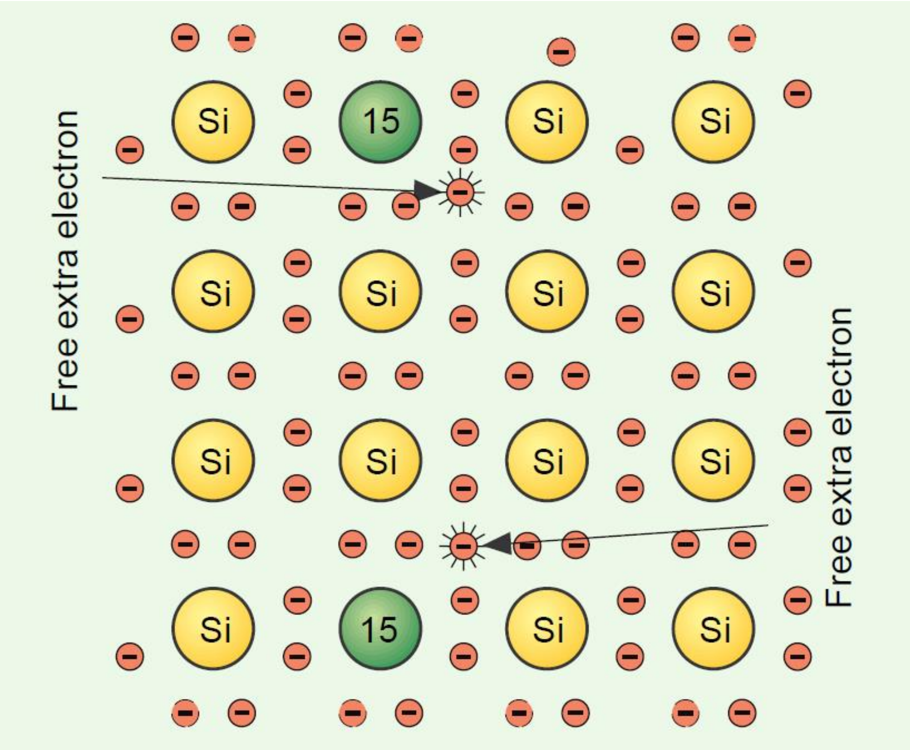
- joncțiunea pn



Efect fotovoltaic

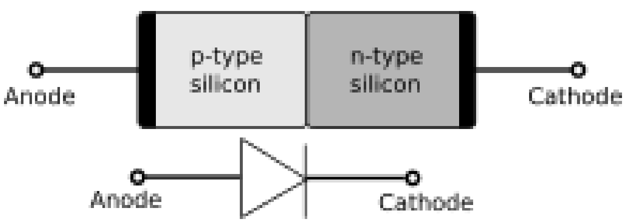
- joncțiunea pn



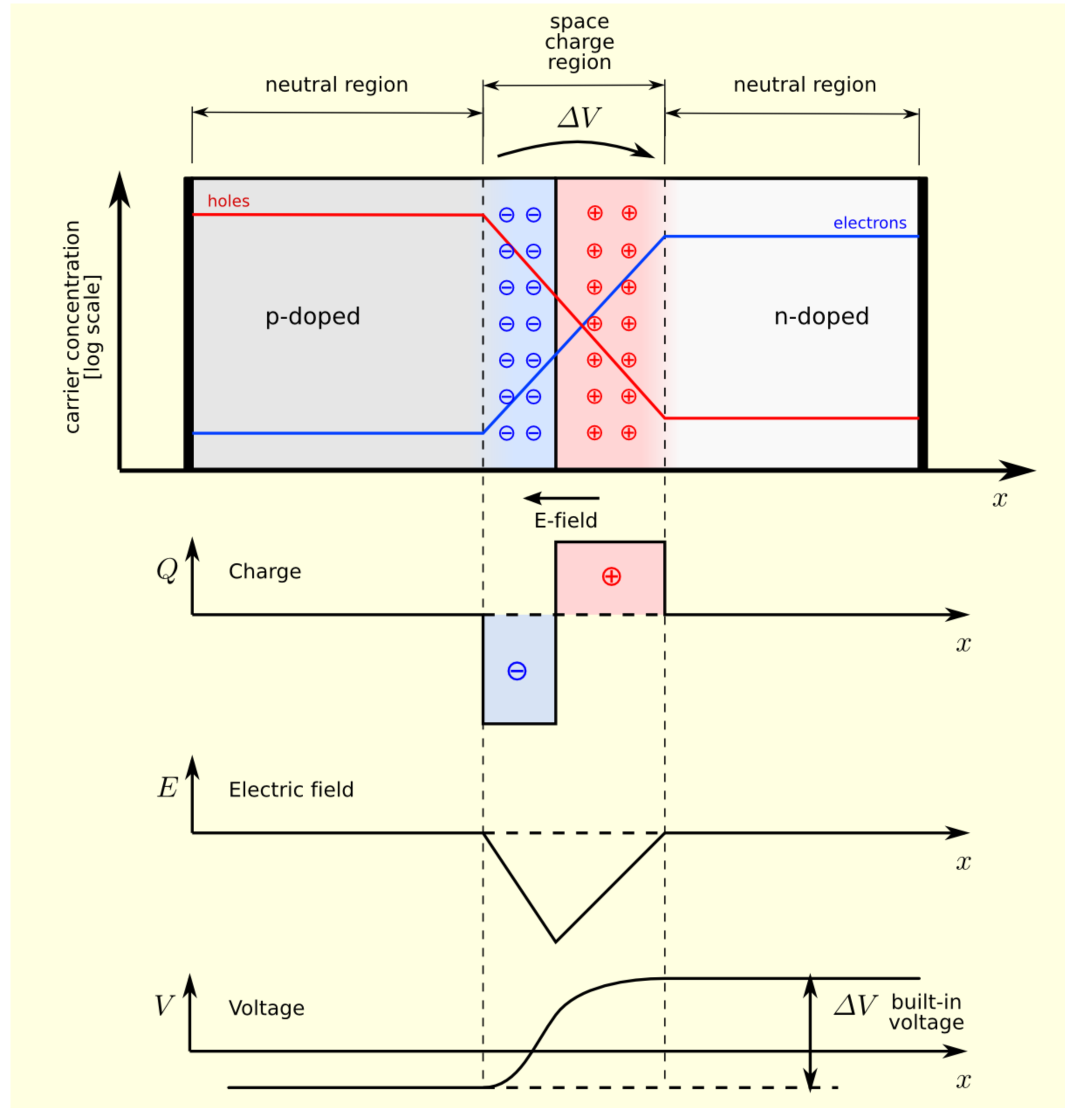


Efect fotovoltaic

- joncțiunea pn

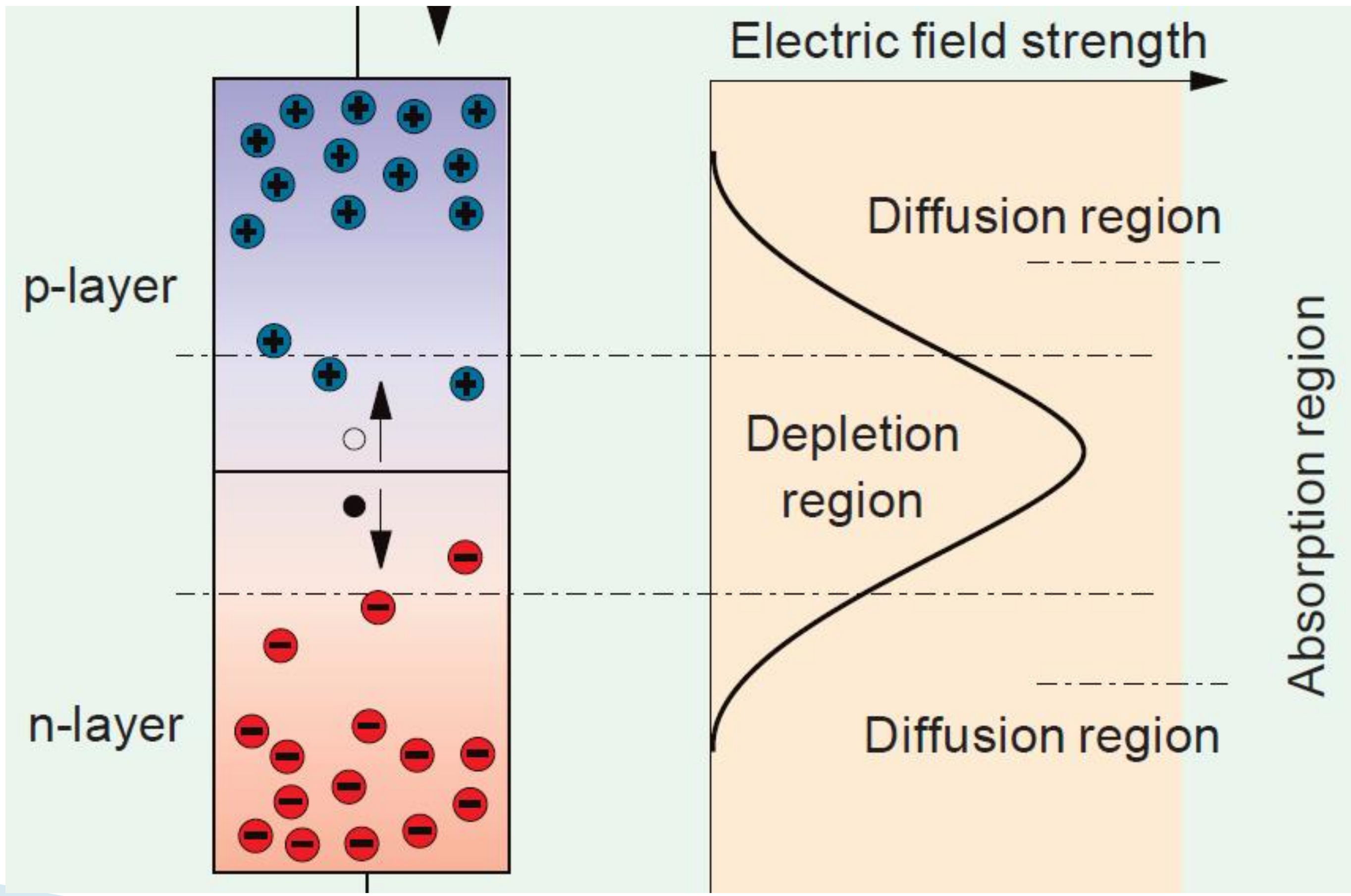


$$V > V_D$$



Efect fotovoltaic

- joncțiunea pn / Fotodioda

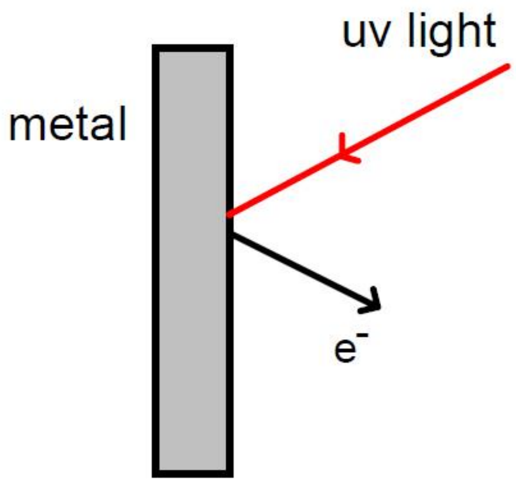


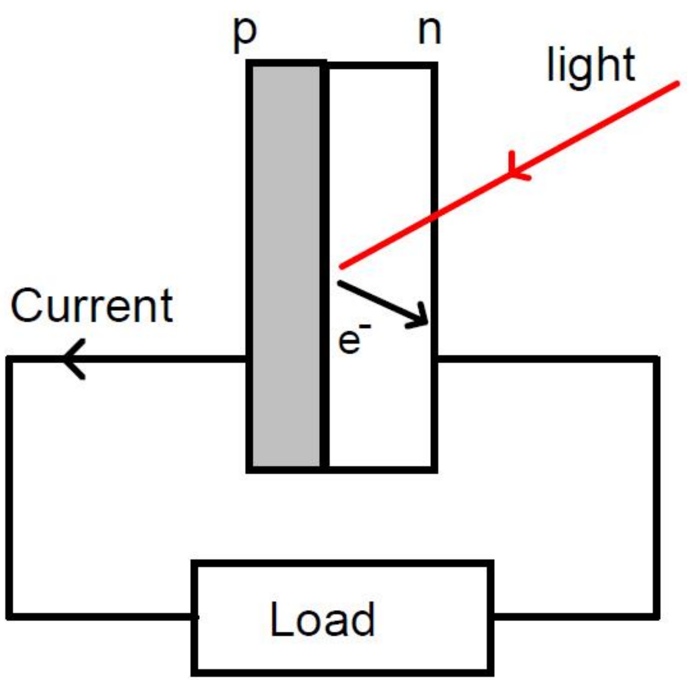
Efect fotovoltaic

- generarea unei perechi electron/gol in interiorul unui material prin absorbtia energiei fotonilor incidenti si cresterea energiei potentiale a electronilor
  - urmat de posibilitatea separarii sarcinilor
- deosebit de conversia:
  - fototermica (energia fotonilor este convertita in caldura - energie cinetica a electronilor)
  - fotochimica (fotosinteza energie potentiala utilizata chimic)
- duce la aparitia unei tensiuni electromotoare si a unui curent intr-un circuit inchis

Efect fotovoltaic

- diferit de efectul fotoelectric (cu toate ca este asemanator ca principiu)



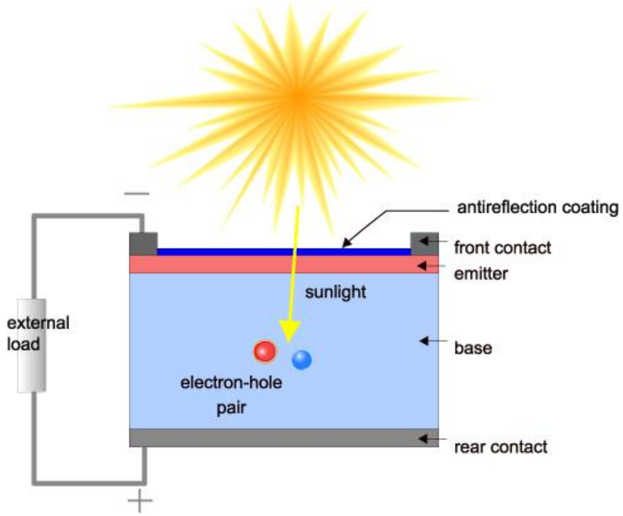


Efect fotovoltaic

- Separarea fizica a sarcinilor este de obicei realizata prin utilizarea unei jonctiuni pn:
  - campul electric generat de distibutia sarcinilor in zona golita de purtatori a jonctiunii
- In principiu o **celula solara** este o **fotodioda** in care:
  - nivelul de semnal optic este ridicat (fortarea prin polarizare inversa externa a extragerii tuturor electronilor generati **nu** e necesara)
  - viteza de lucru nu e importanta (accelerarea iesirii din dispozitiv a electronilor generati **nu** e necesara)

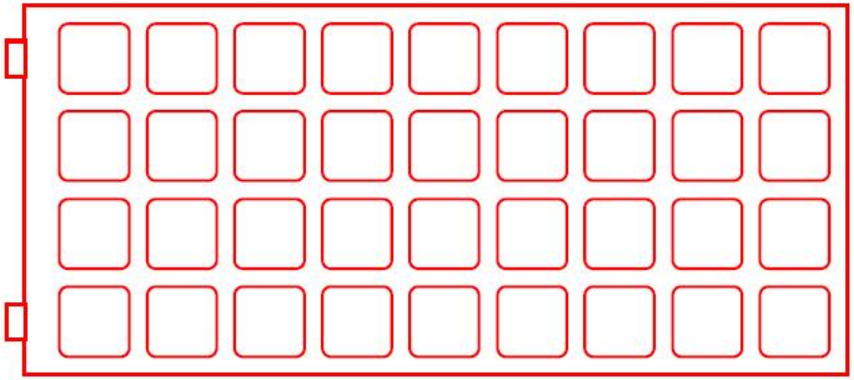
Celula solara (fotovoltaica)

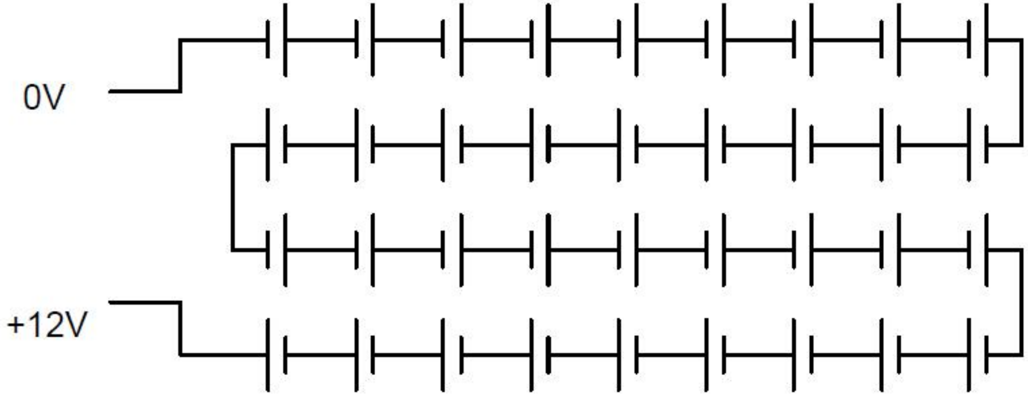
- in principiu o dioda
  - cu arie mare (~100cm^2)
  - cu suprafata tratata antireflectorizant
  - genereaza o tensiune electromotoare de 0.5÷1V
  - genereaza curenti de scurtcircuit de x0 mA/cm^2



Celula solara (fotovoltaica)

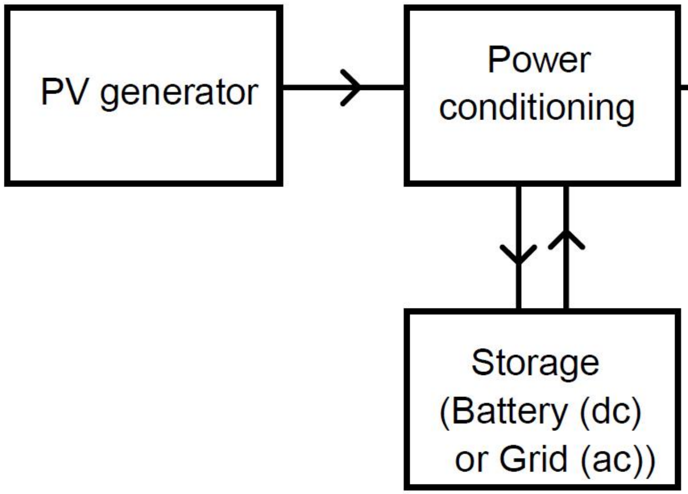
- pentru utilizare in practica
  - module de 28 – 36 de celule conectate in serie
  - creste tensiunea la 12V (tipic)

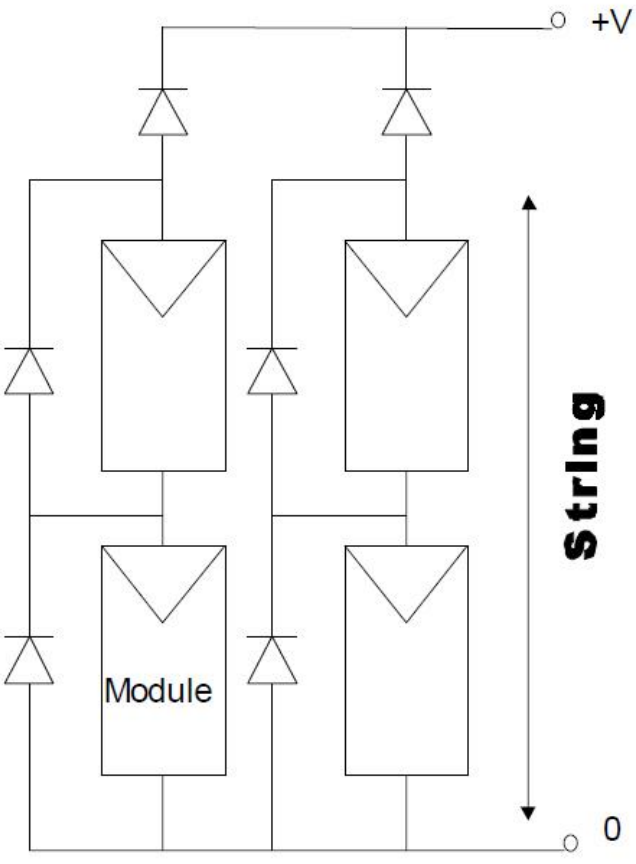




Celula solara (fotovoltaica)

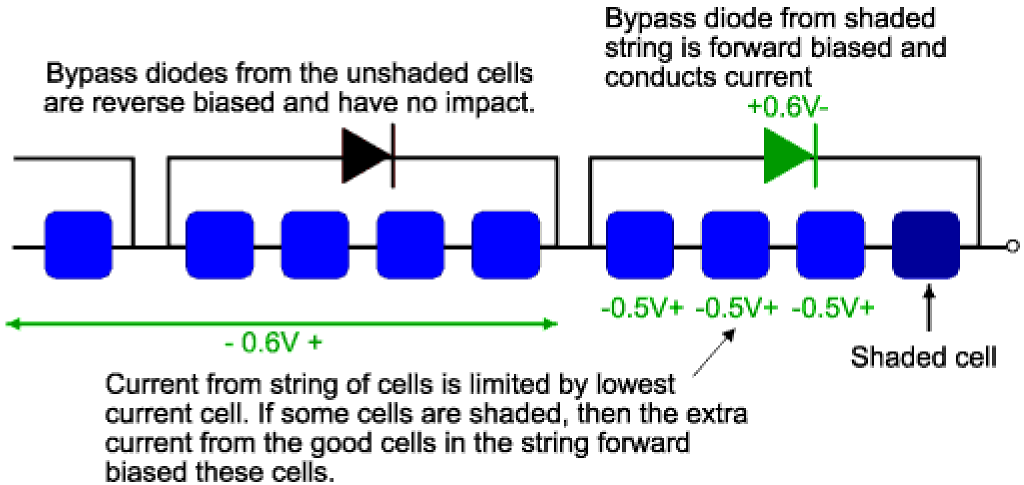
- pentru utilizare in practica
  - modulele sunt conectate in serie si/sau paralel pentru obtinerea tensiunilor/curentilor necesari pentru aplicatie

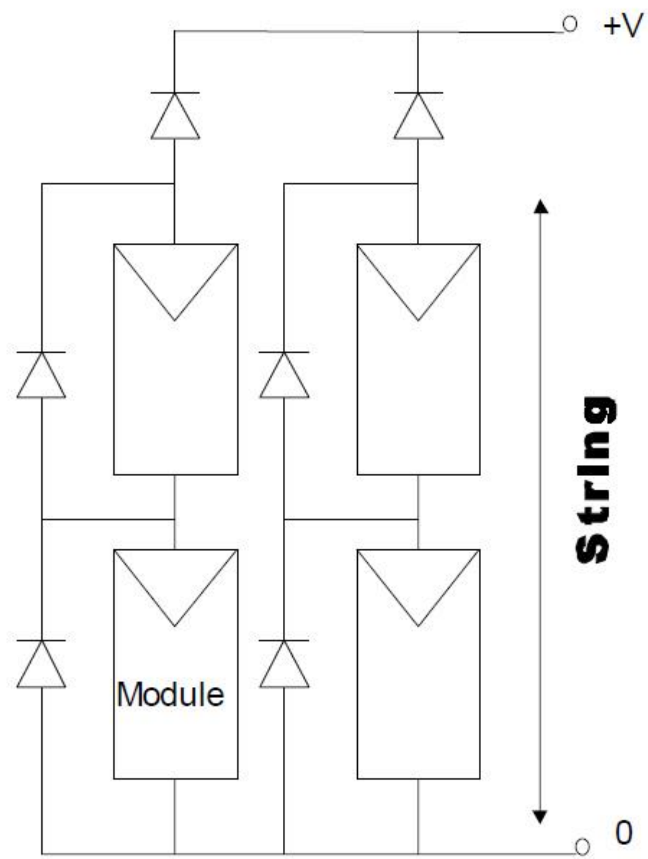




Celula solara (fotovoltaica)

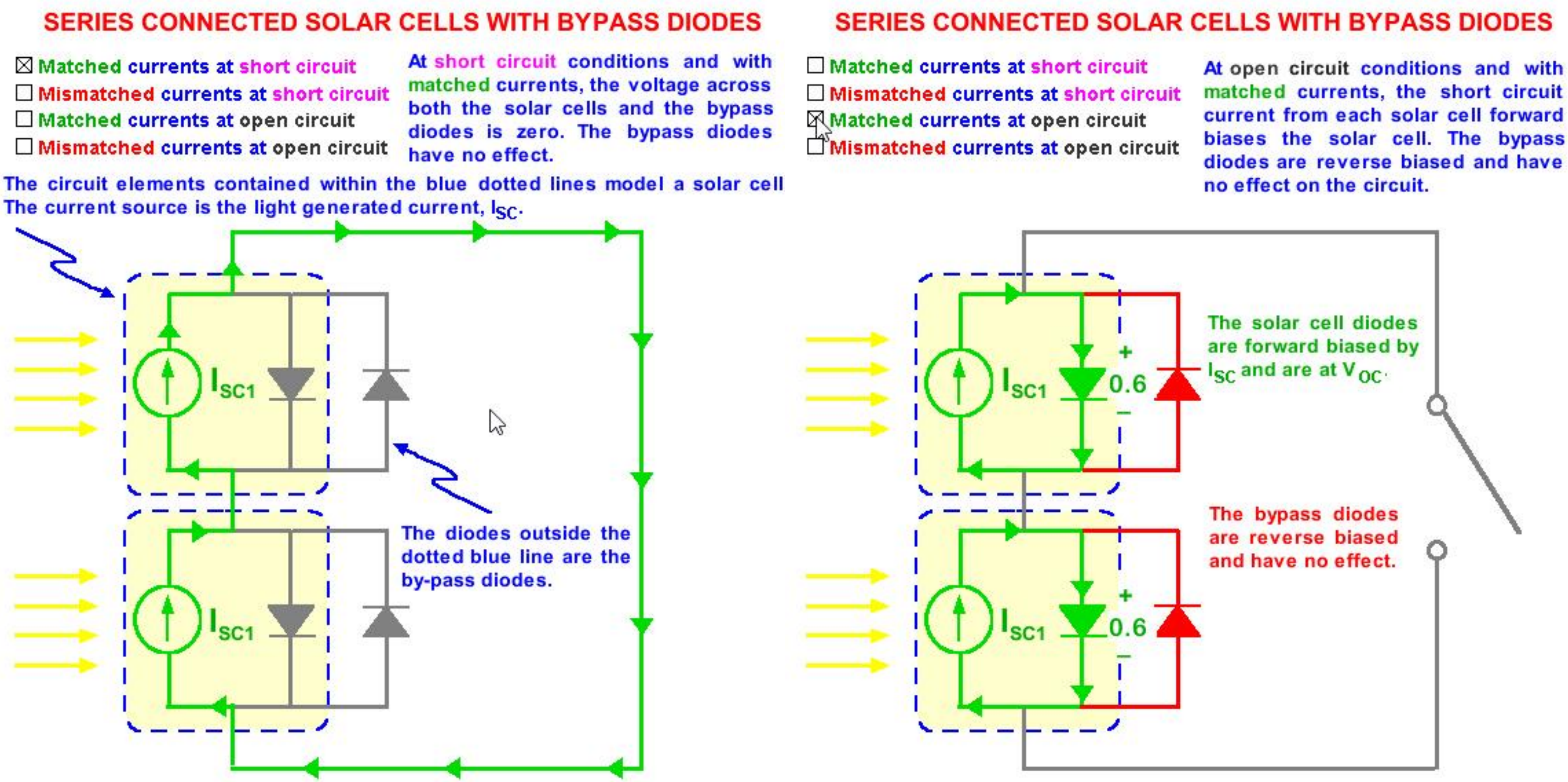
- pentru utilizare in practica
  - diode pentru flexibilitate





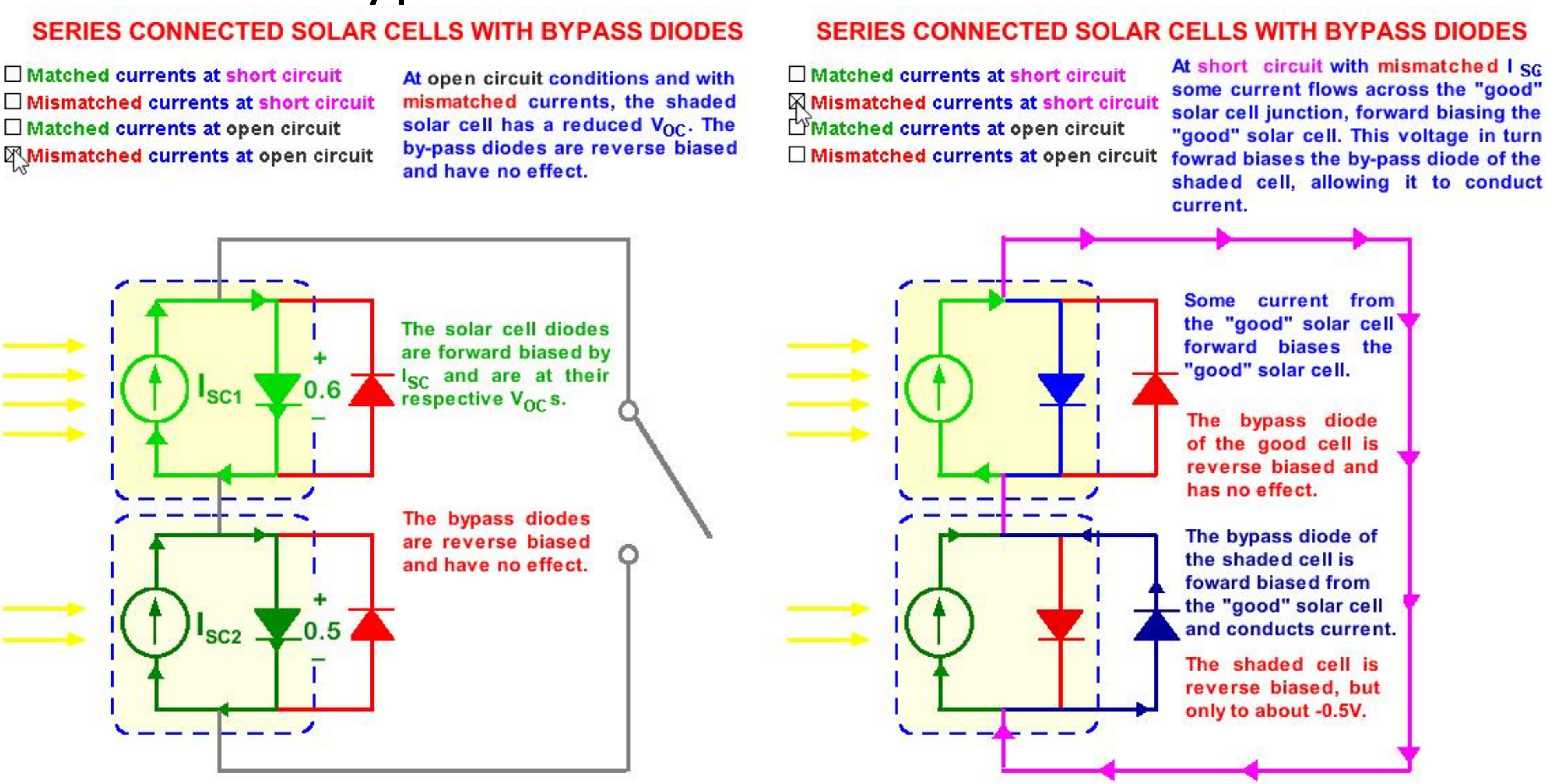
Celula solara (fotovoltaica)

- Diode bypass



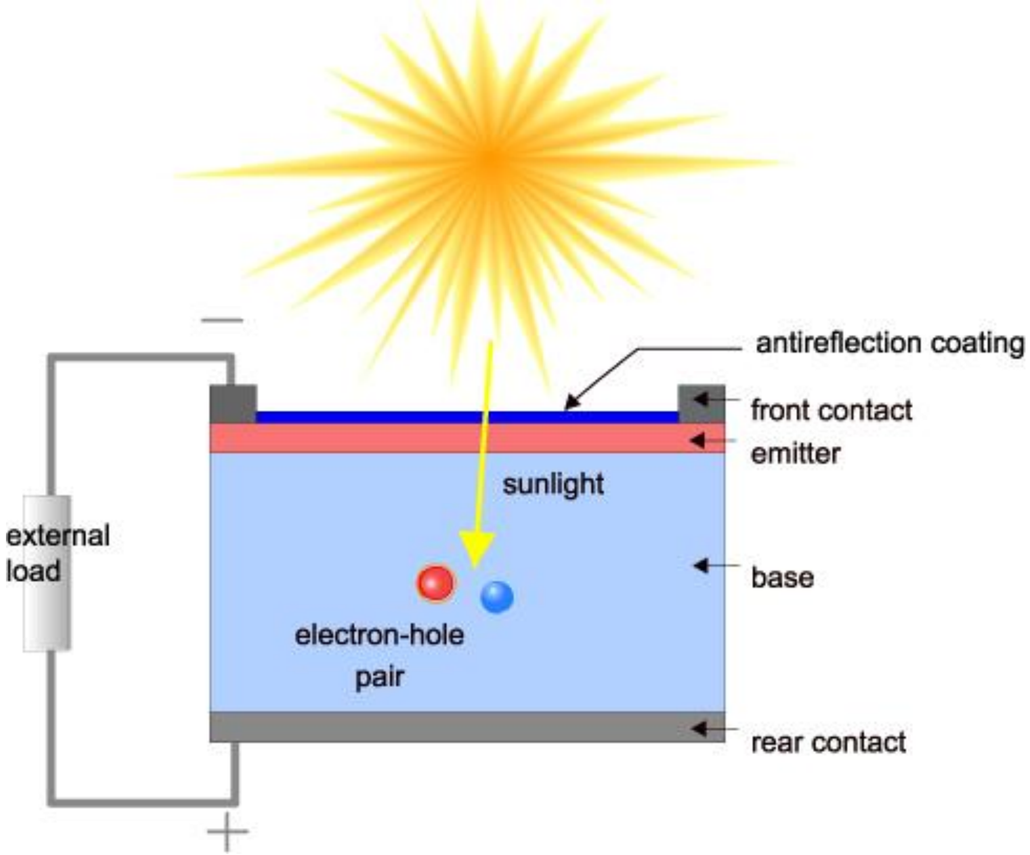
Celula solara (fotovoltaica)

- Diode bypass



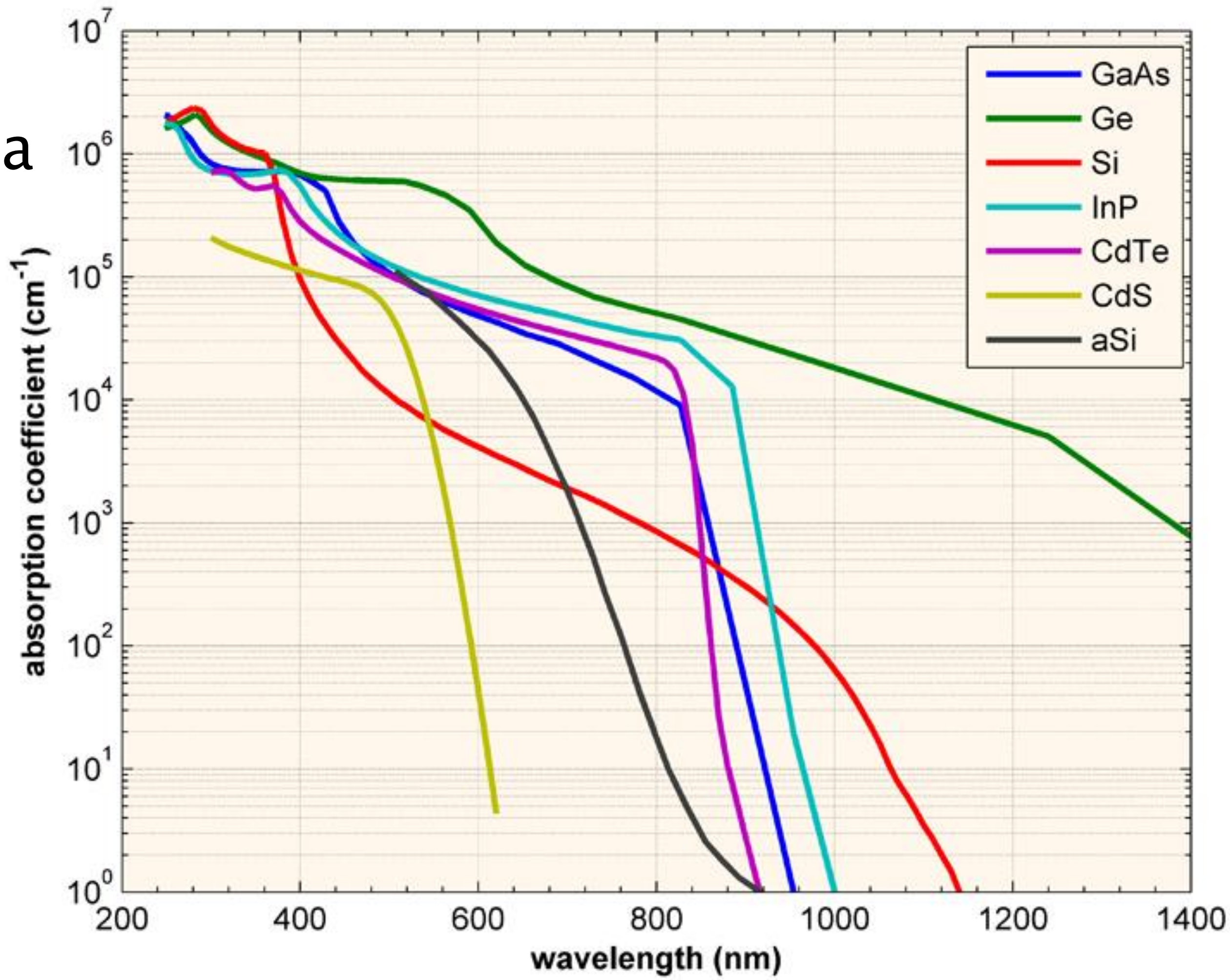
Celula solara (fotovoltaica)

- in principiu o dioda



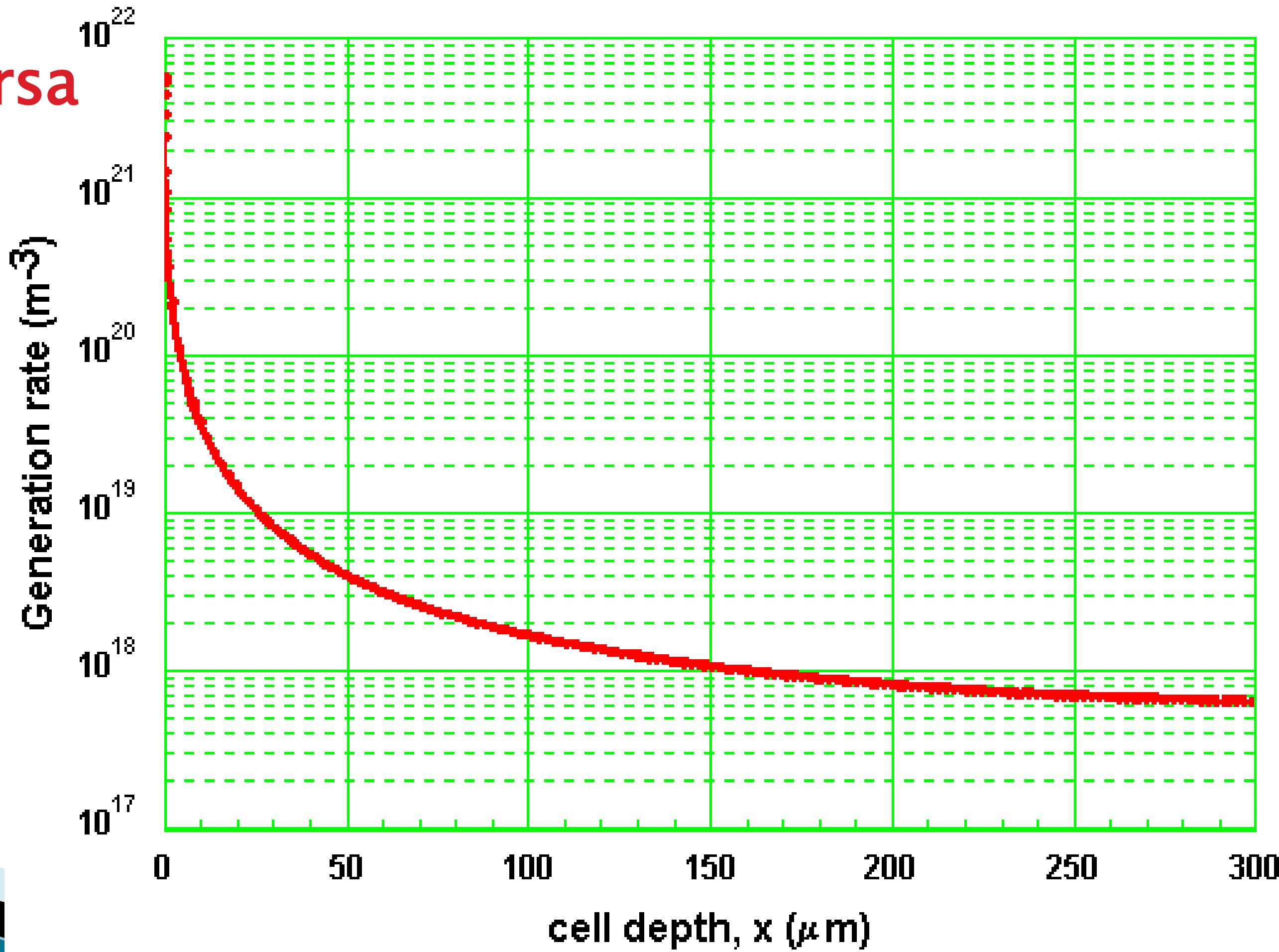
Celula solara

- probabilitate de generare a purtatorilor depinde de
  - **material**
  - distanta parcursa



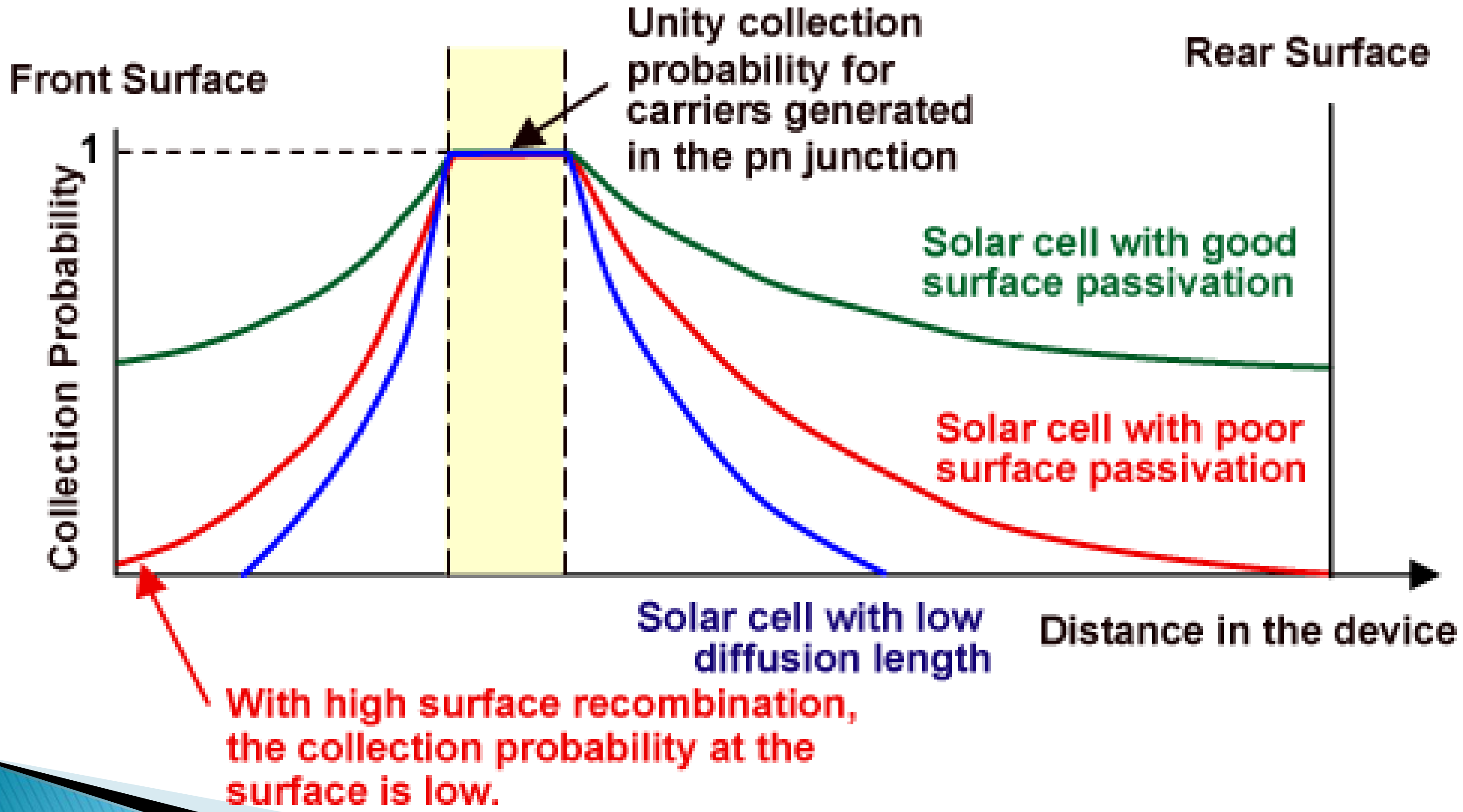
Celula solara

- probabilitate de generare a purtatorilor depinde de
  - material
  - distanta parcursa



Celula solara

- probabilitate de captura a purtatorilor



Celula solara/Fotodioda

- Energia necesara pentru eliberarea unei perechi electron gol

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

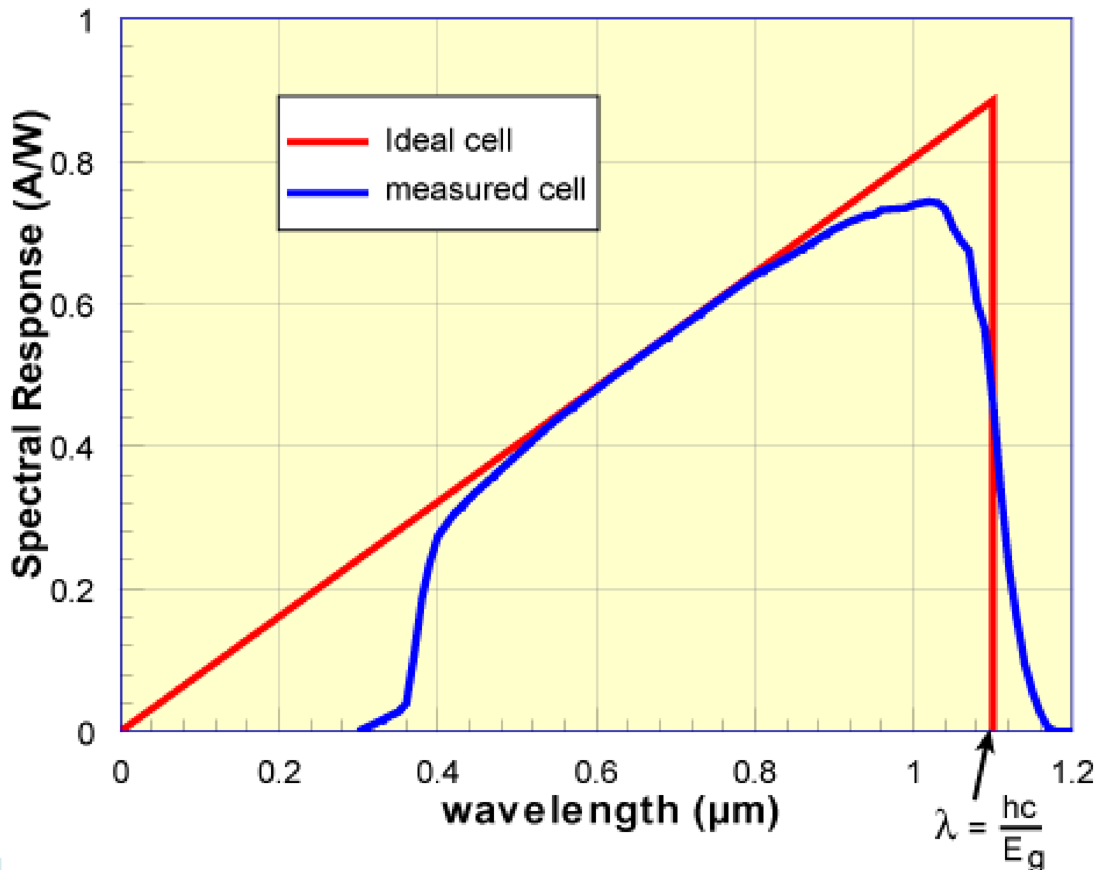
- Lungime de unda de taiere

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

- Coeficientul de absorbtie are valoare mare la lungimi de unda reduse
- Ca urmare comportarea **tuturor** materialelor este de tip trece banda

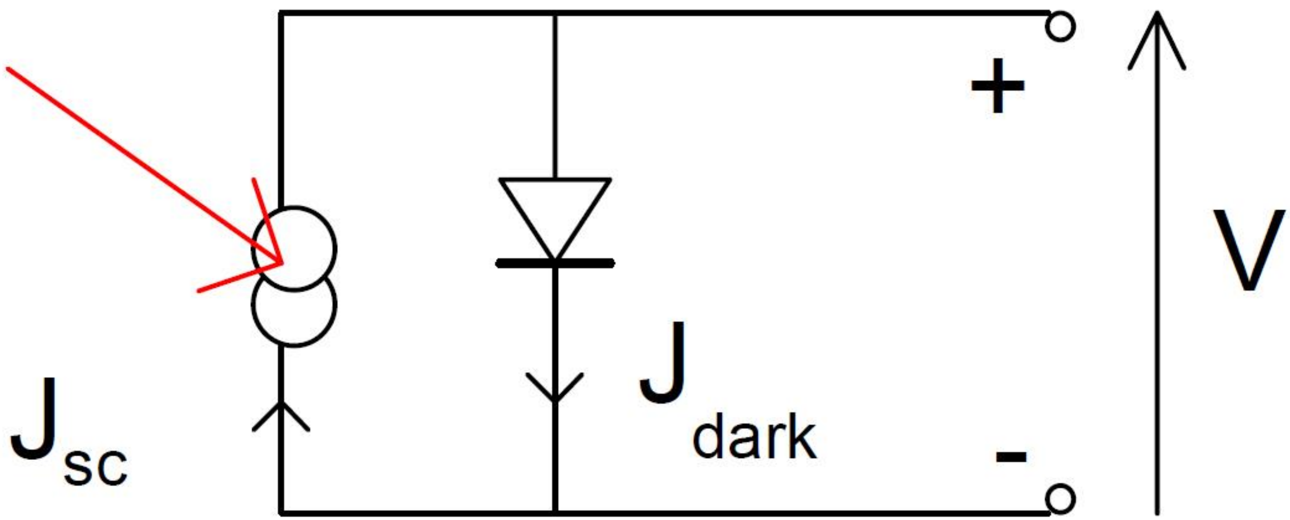
Celula solara

- raspuns spectral



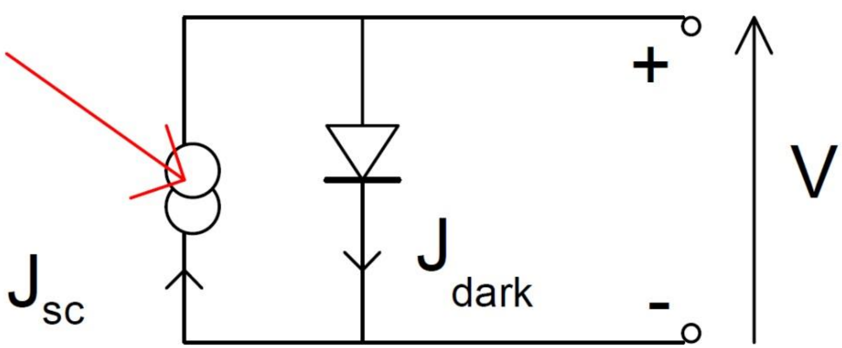
Celula solara

- Schema echivalenta
  - dioda
  - sursa de curent generat de fluxul de fotoni incident



Celula solara

- Schema echivalenta
  - dioda
  - sursa de curent generat de iluminarea energetica incidenta



- curent de intuneric

$$I_d(V) = I_0 \cdot \left(e^{eV/KT} - 1\right)$$

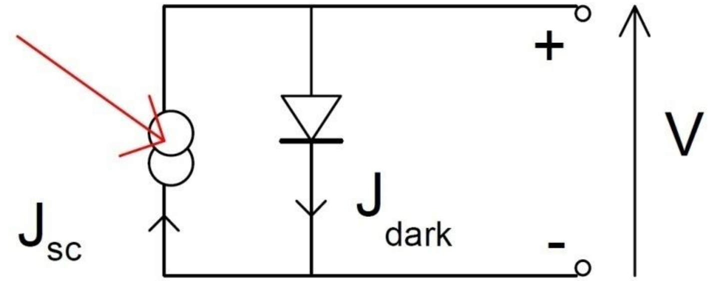
- adaugarea curentului generat de fotoni

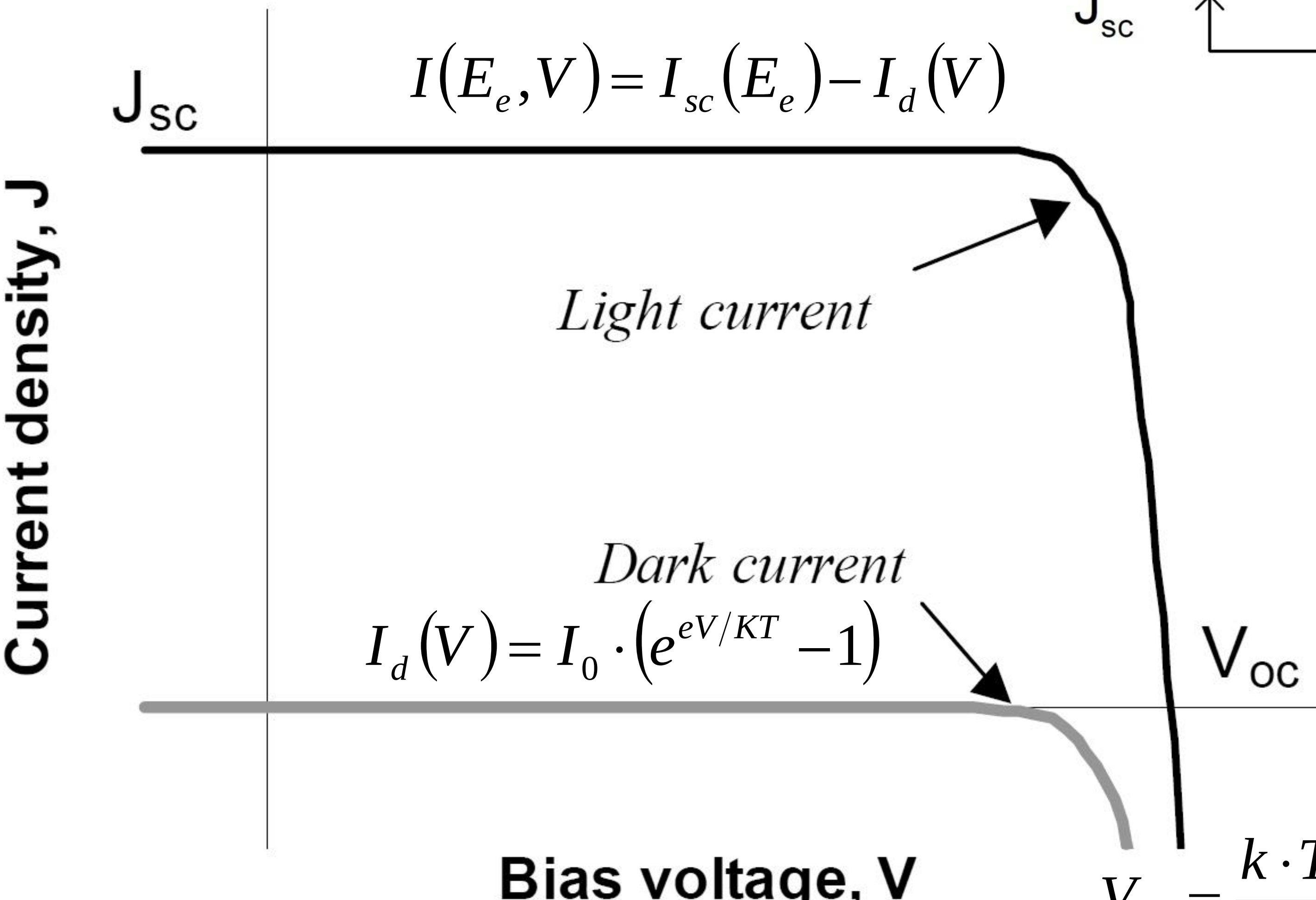
$$I(E_e, V) = I_{sc}(E_e) - I_d(V)$$

- tensiunea in gol

$$V_{oc} = \frac{k \cdot T}{e} \cdot \ln\left(\frac{I_{sc}(E_e)}{I_0} - 1\right)$$

Celula solara

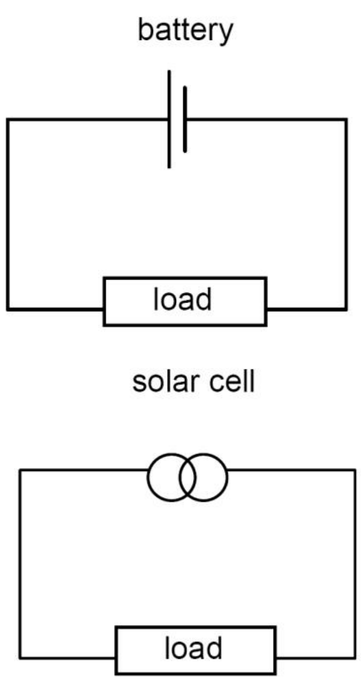


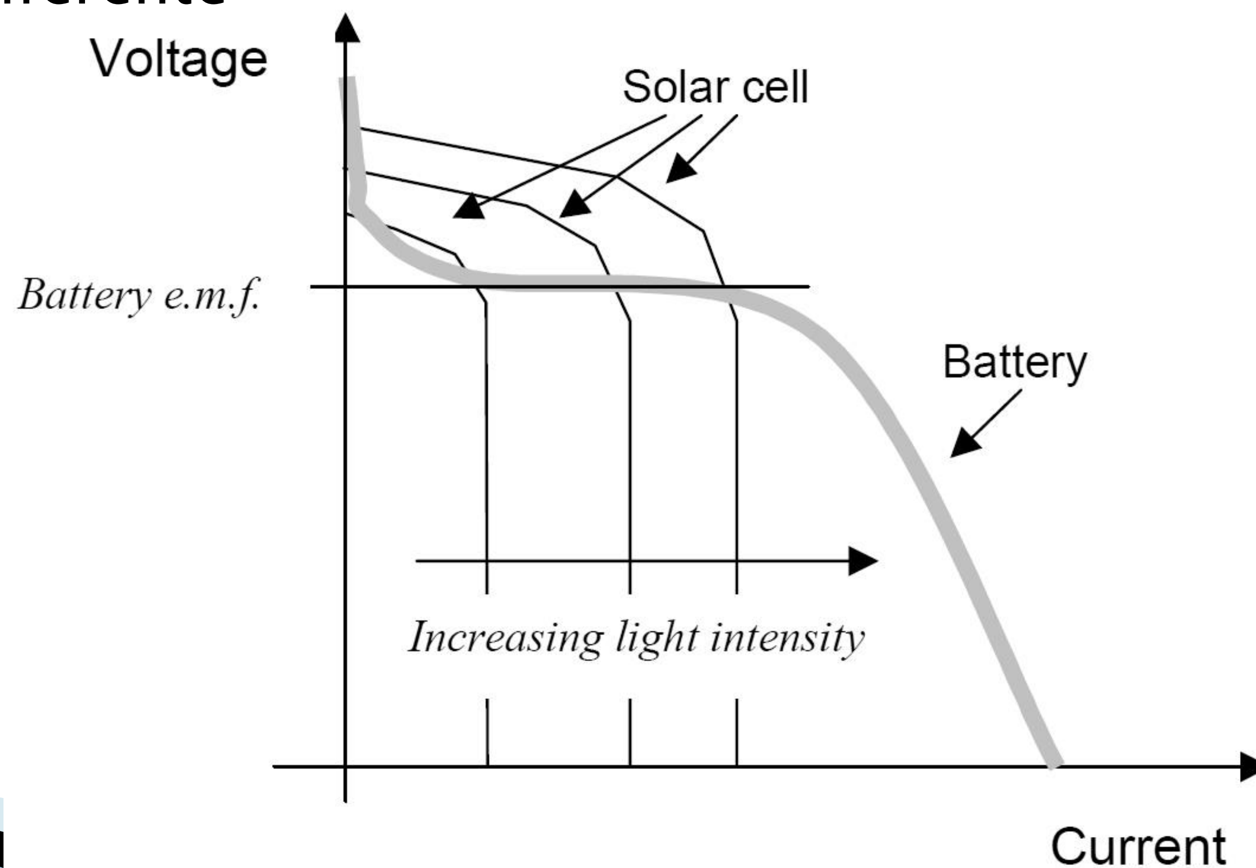


$$V_{oc} = \frac{k \cdot T}{e} \cdot \ln\left(\frac{I_{sc}(E_e)}{I_0} - 1\right)$$

Celula solara

- poate fi folosita in loc de baterie intr-un circuit electric
  - cu anumite diferente



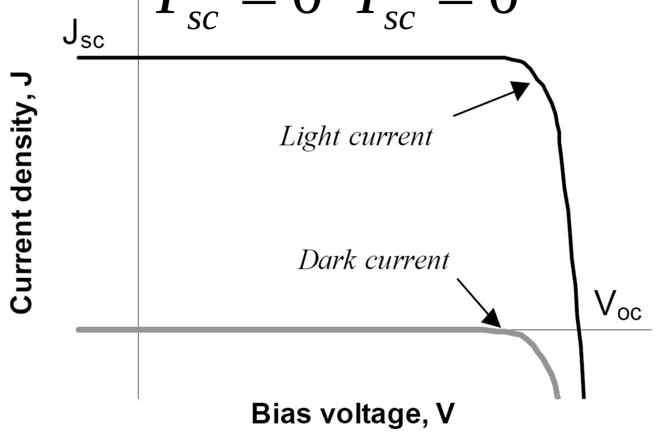


Putere generata

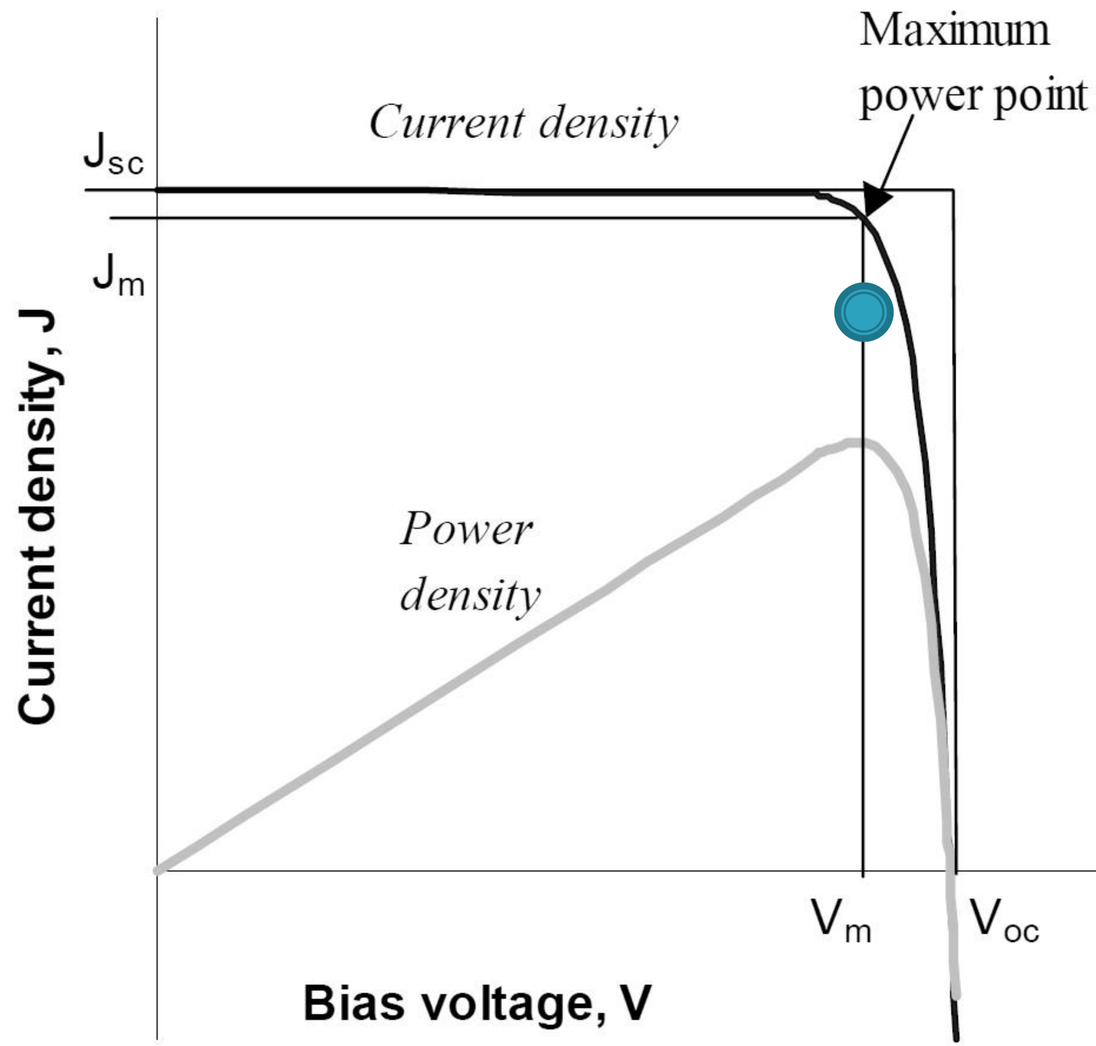
- Putere generata

$$P = V \cdot I$$

$$P_{sc} = 0 \cdot I_{sc} = 0$$

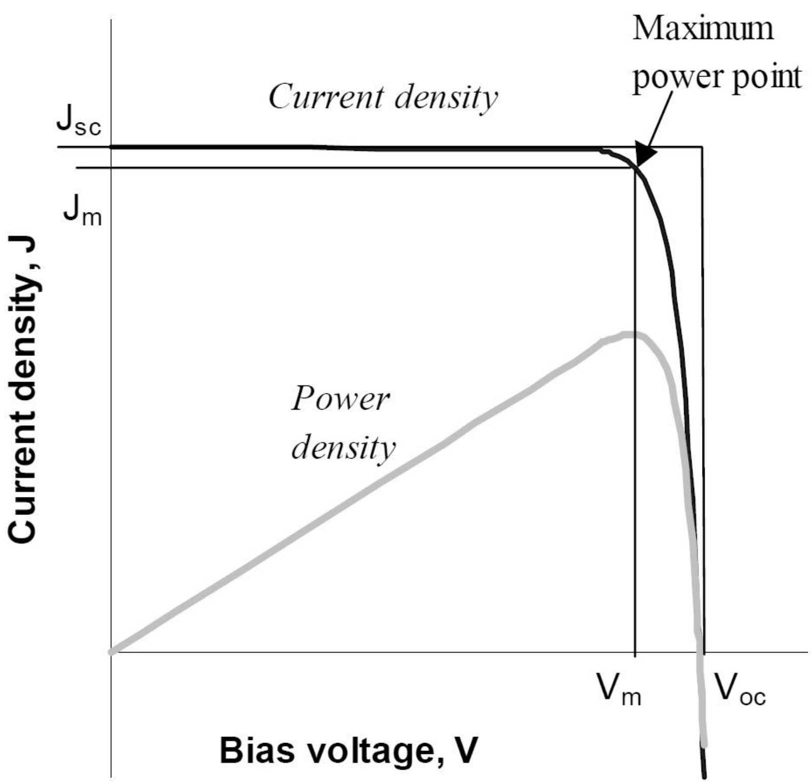


$$P_{oc} = V_{oc} \cdot 0 = 0$$



Putere generata

- Putere generata

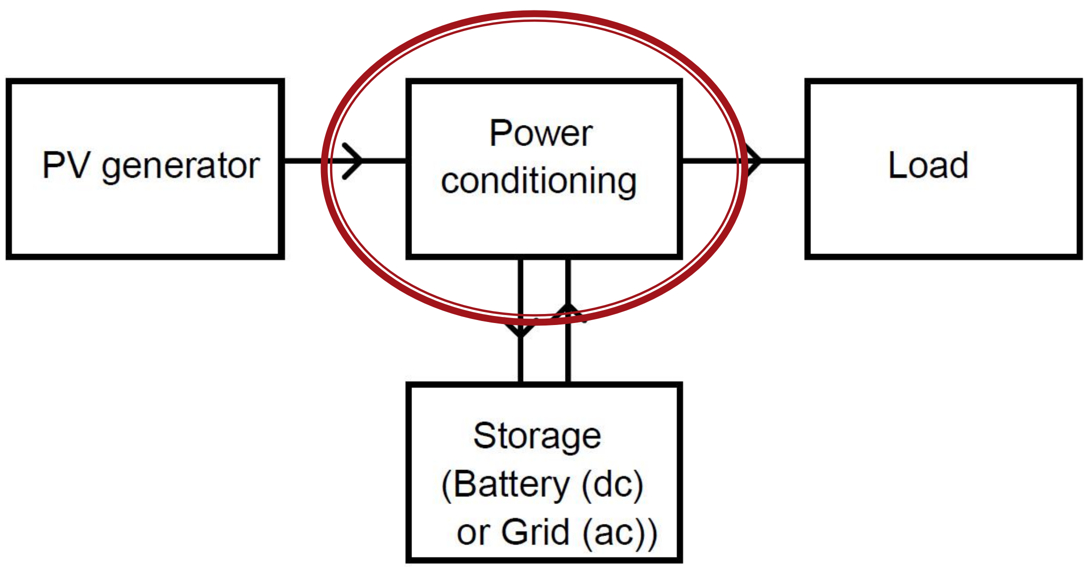


$$P_m = V_{pm} \cdot I_{pm}$$

- Valorile de curent si tensiune pentru putere maxima sunt date de catalog, circuitul de conditionare care urmeaza dupa celule poate fi **optimizat** sa functioneze la aceste valori

Putere generata

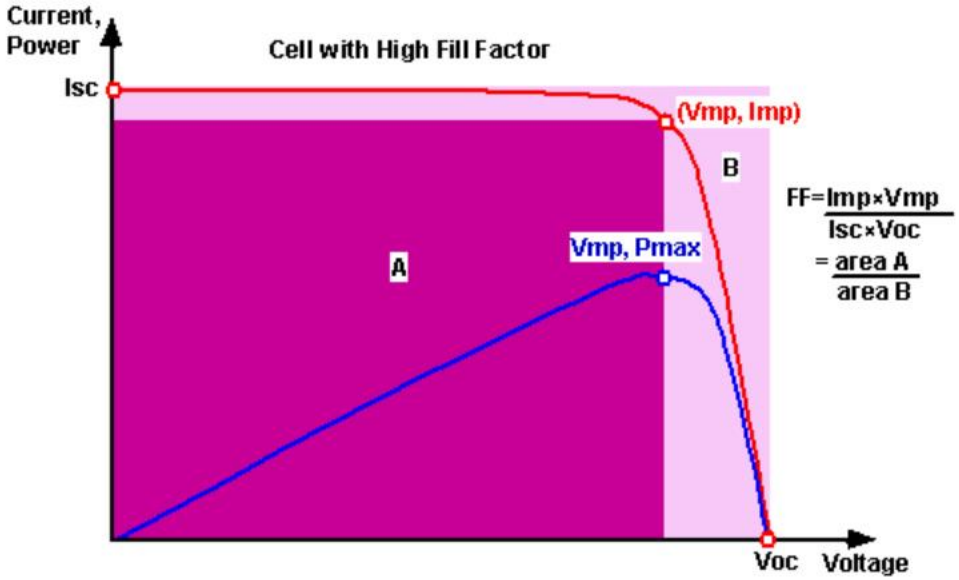
- Controlerul de incarcare este responsabil pentru detectarea si urmarirea puctului de putere maxima
  - MPPT – Maximum power point tracking



Celula solara

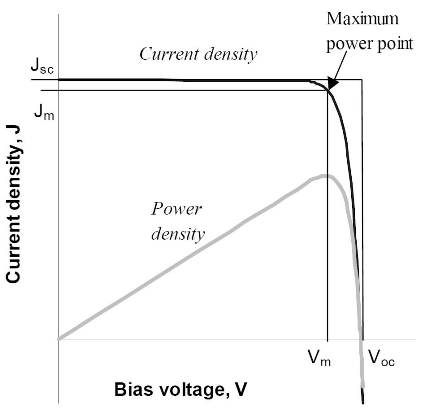
- Factor de umplere

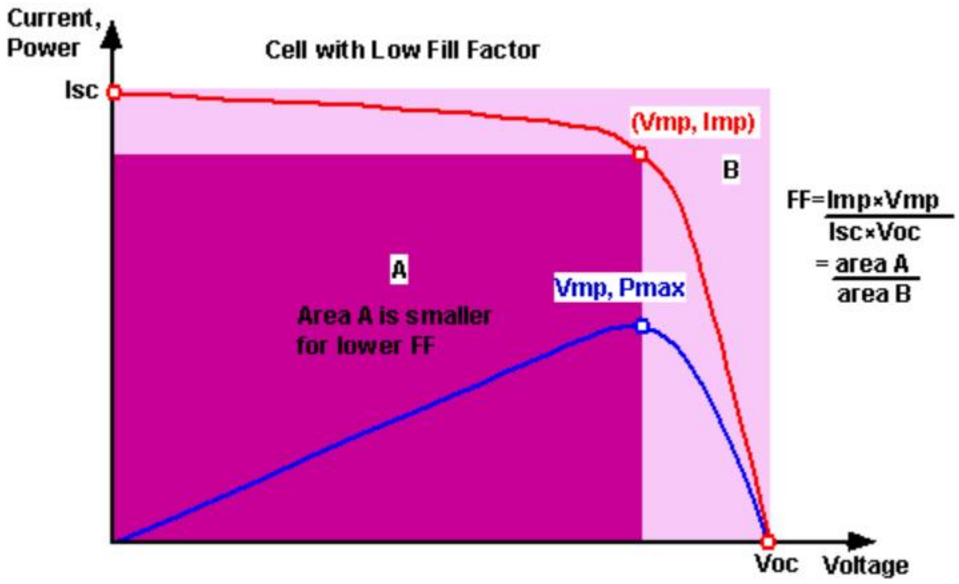
$$FF = \frac{V_{pm} \cdot I_{pm}}{V_{oc} \cdot I_{sc}}$$



- o masura a calitatii celulei
  - dependent de material

$$P_m = V_{pm} \cdot I_{pm}$$

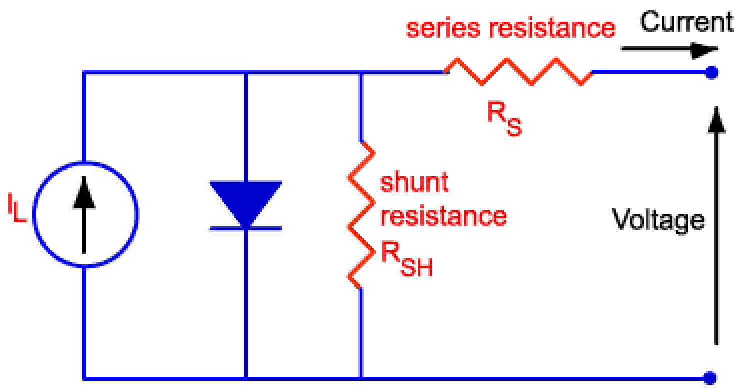


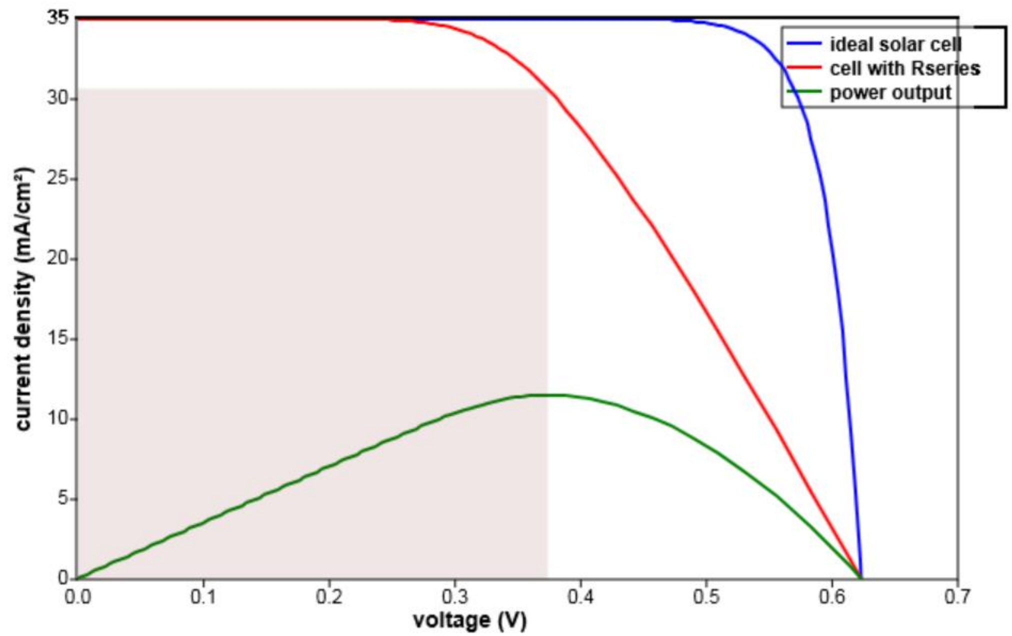


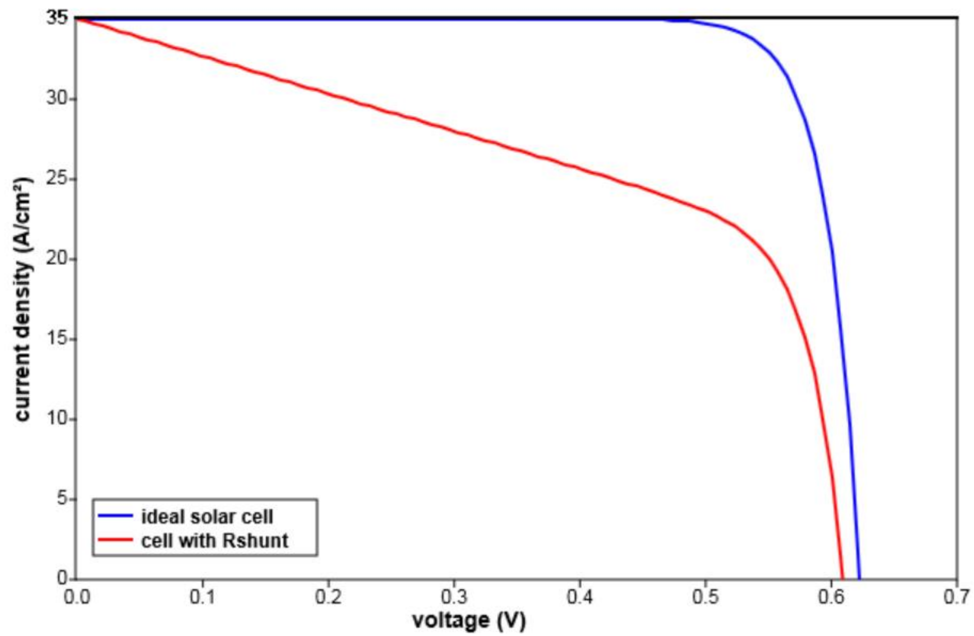
Efect pierderi

- Rezistenta serie
  - rezistenta echivalenta a semiconductorului utilizat
  - rezistenta jonctiunilor metal/semiconductor
  - rezistenta contactului metalic al anodului si colectorului
- Rezistenta paralel
  - generata de defecte de fabricatie

Efect pierderi

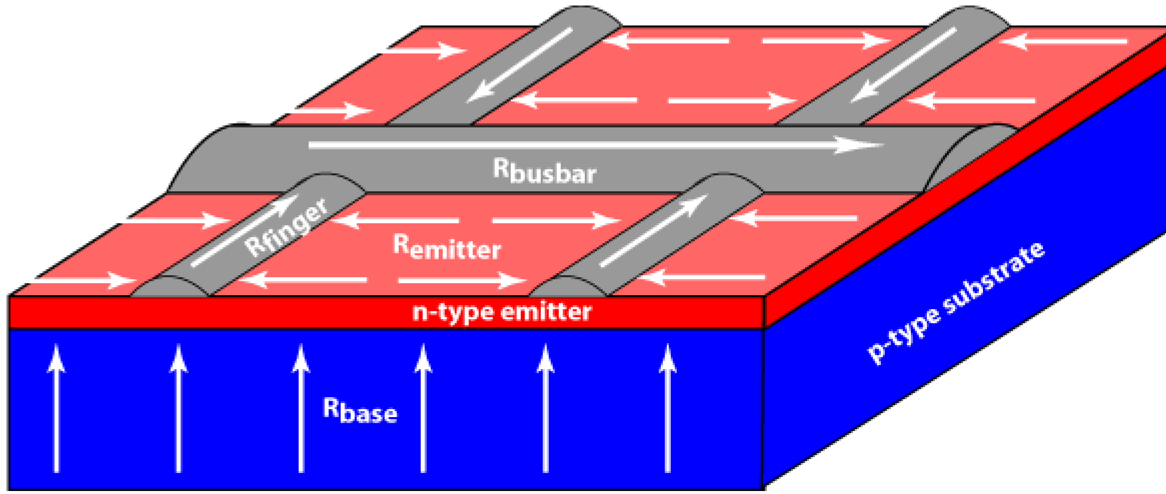


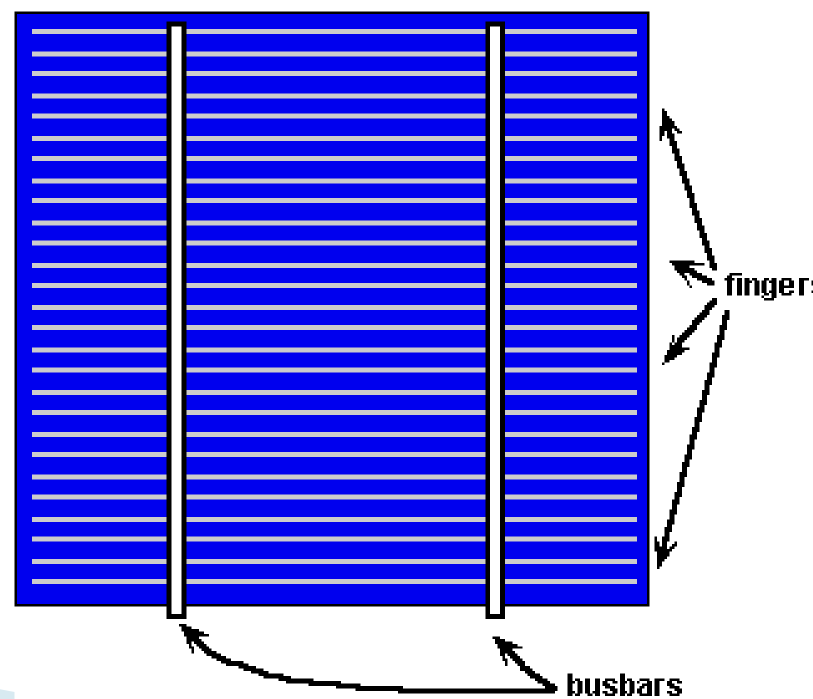




Rezistenta serie

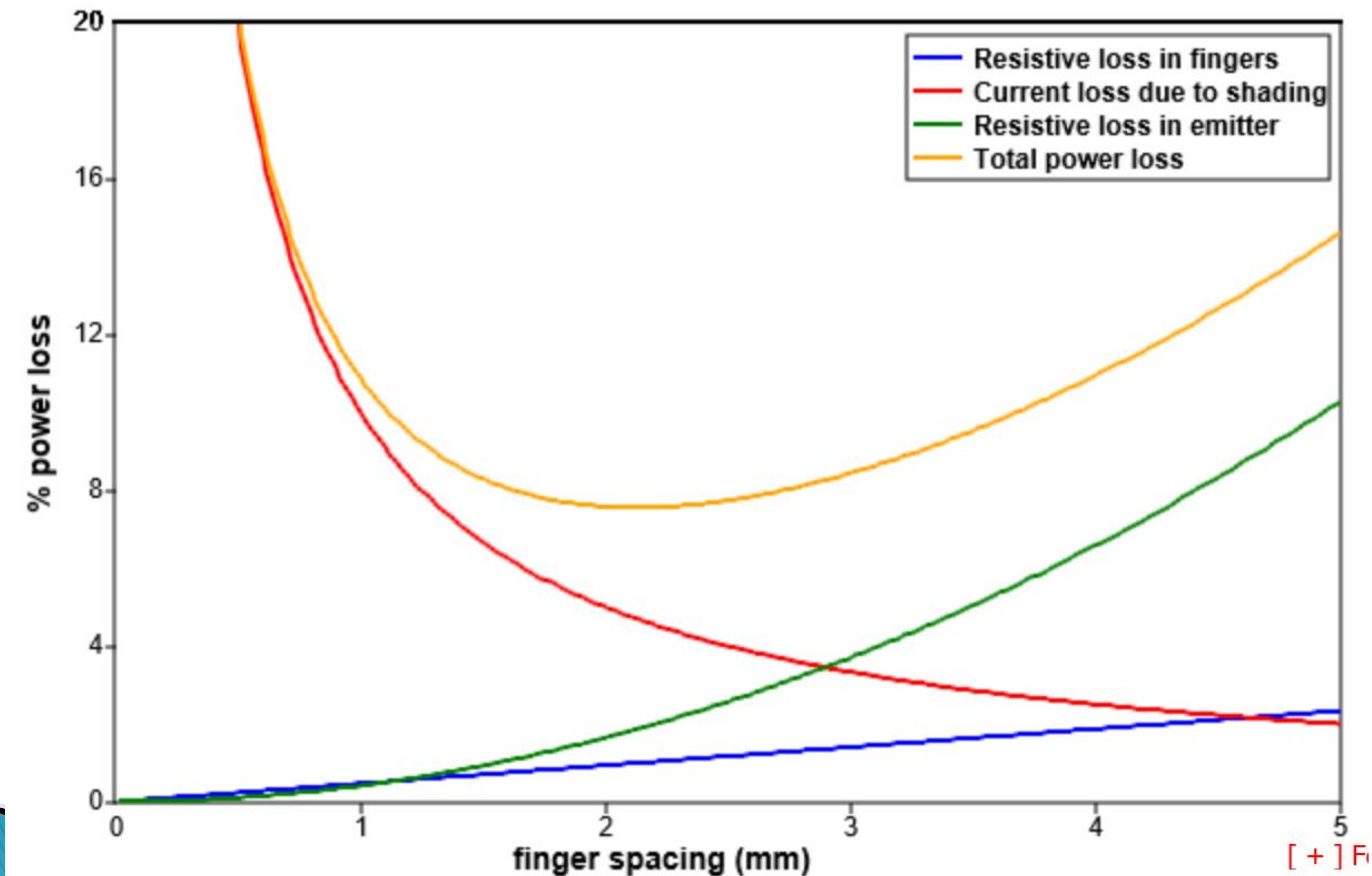
- Minimizare Rs
  - bare colectoare
  - “degete”
- Compromis
  - rezistenta
  - suprafata metalica reflectorizanta





Rezistenta serie

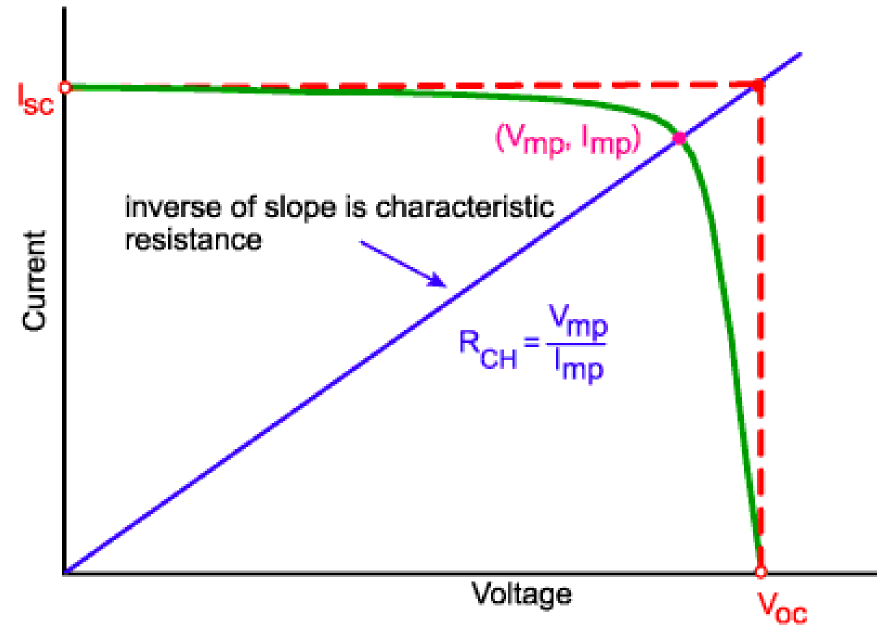
- Comprimis rezistenta/suprafata metalica



Rezistenta caracteristica

- Raportul intre V si I cand celula lucreaza la eficienta maxima

$$R_C = \frac{V_{pm}}{I_{pm}} \approx \frac{V_{OC}}{I_{SC}}$$



- Daca sarcina este egala cu RC, celula lucreaza la eficienta maxima
  - Tipic, celulele comerciale opereaza la tensiune mica si curent mare
    - conexiunile la celule trebuie sa aiba rezistente de ordinul mΩ

$$R_C = \frac{0.6V}{9A} \approx 0.067\Omega$$

Eficienta celulei solare

- raportul dintre puterea electrica generata si puterea optica incidenta

$$\eta = \frac{P_m}{P_o} = \frac{V_{pm} \cdot I_{pm}}{P_o}$$

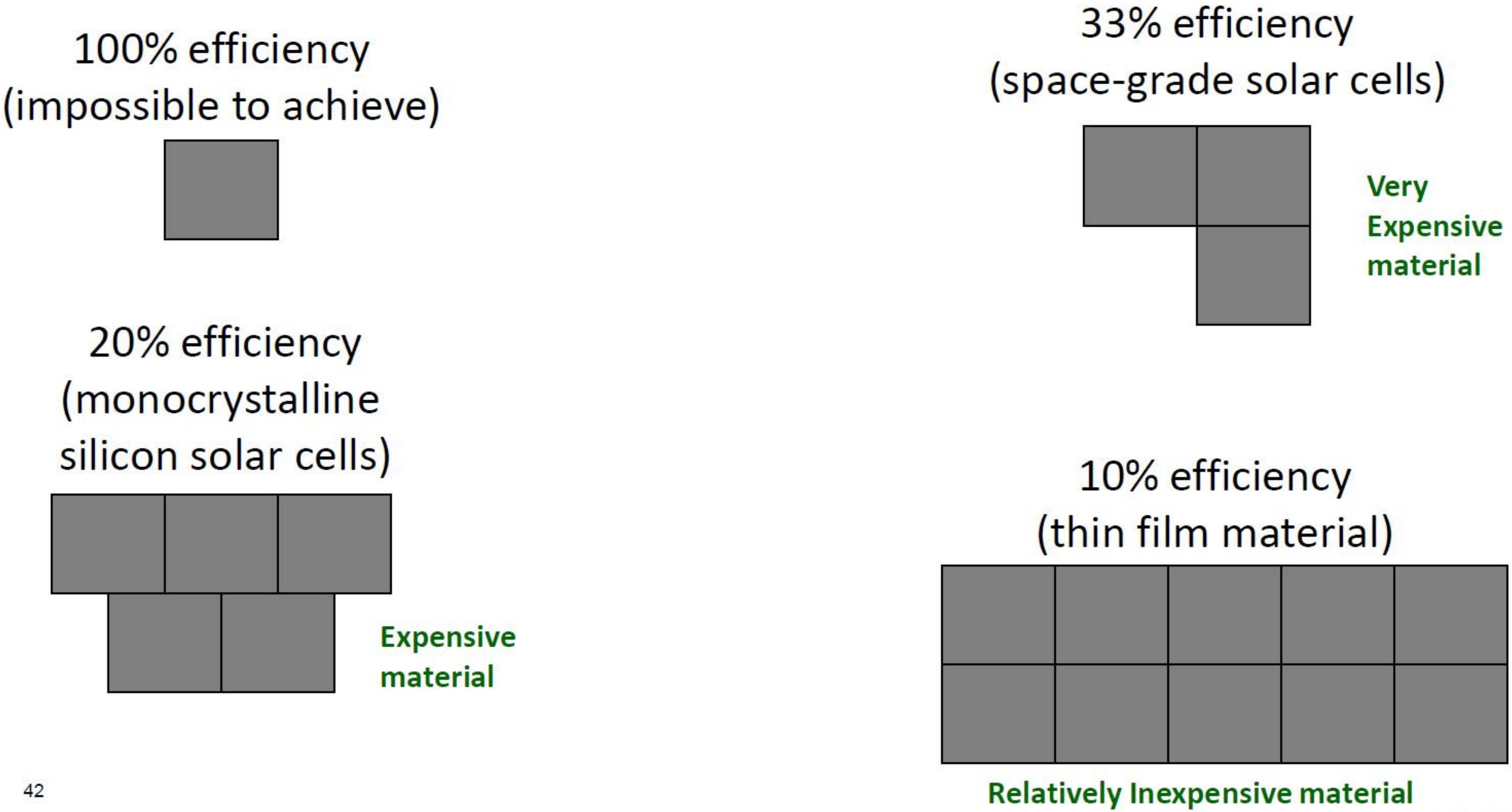
$$\eta = \frac{P_m}{P_o} = \frac{V_{oc} \cdot I_{sc} \cdot FF}{P_o}$$

- Puterea optica depinde de fluxul energetic al luminii incidente si suprafata celulei

$$P_o = S \cdot \int_0^\infty \Phi_e(\lambda) d\lambda$$

Eficienta celulei solare

- determina suprafata necesara pentru obtinerea unei puteri dorite



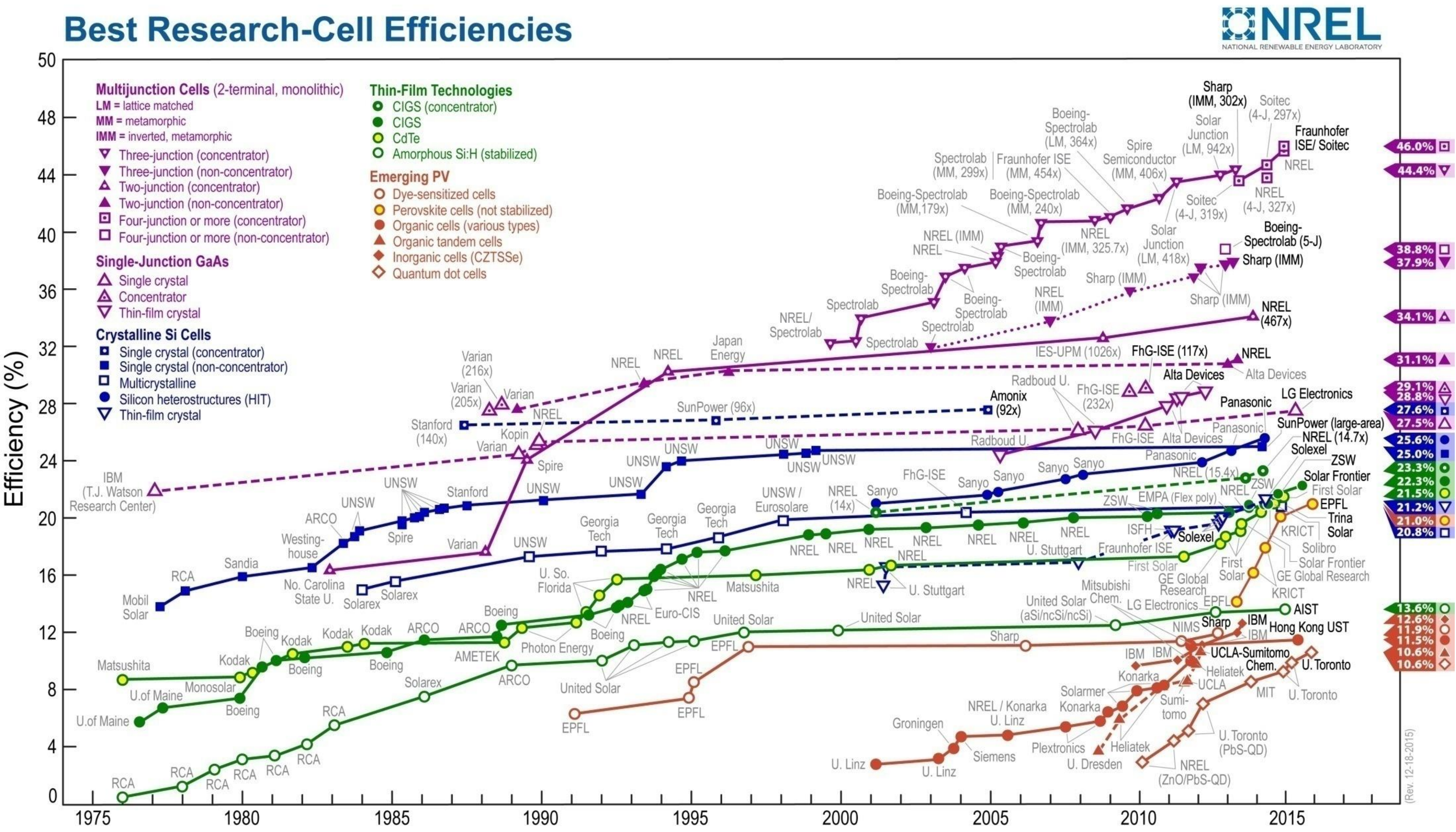
Eficienta celulei solare

- Exista o limita maxima teoretica pentru fiecare material semiconductor
  - fiecare material are o banda spectrala proprie, **mai mica** decat banda spectrala a soarelui
- valorile nu sunt foarte mari
  - din motive economice, recordurile nu sunt repetate in practica

Table 1.1. Performance of some types of PV cell [Green *et al.*, 2001].

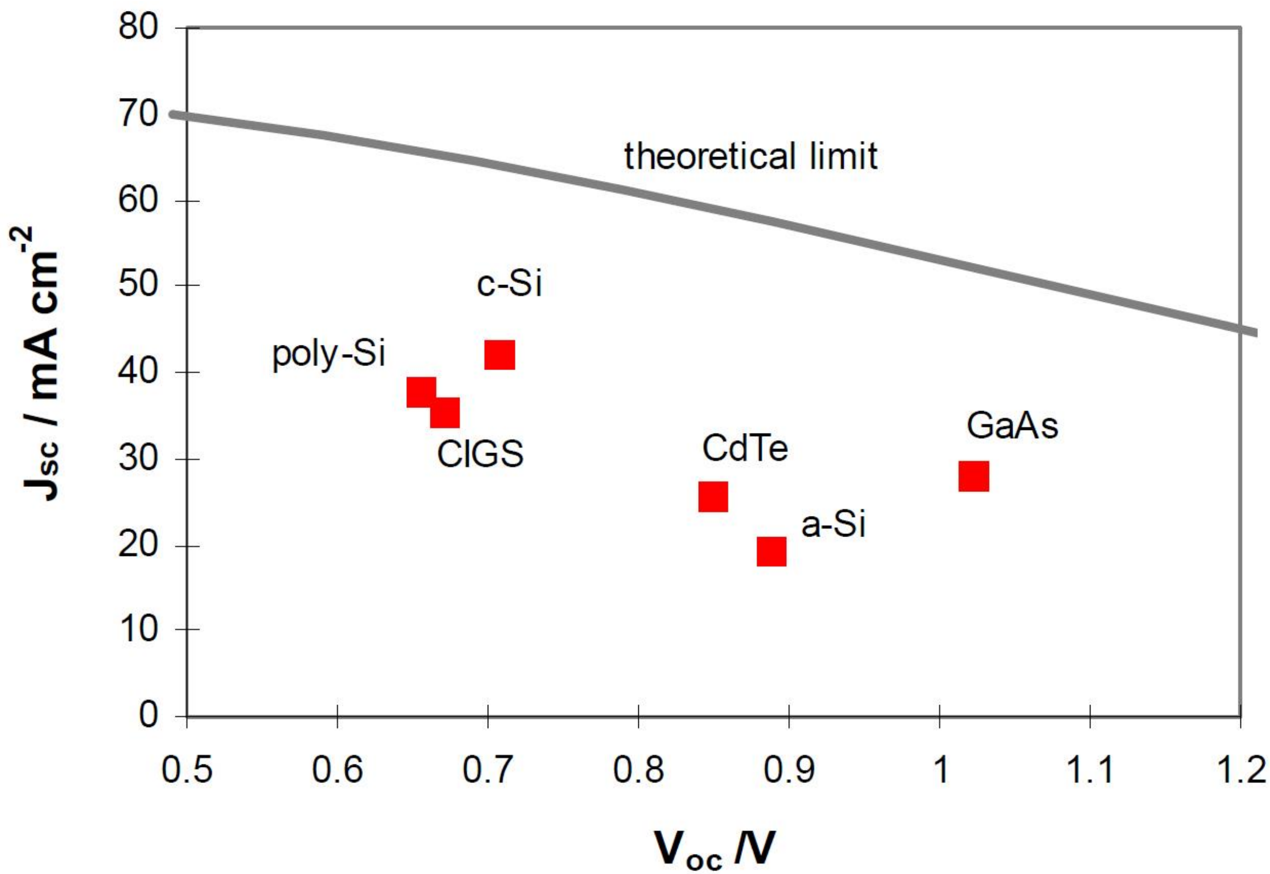
Cell Type	Area (cm^2)	V_{oc} (V)	J_{sc} (mA/cm^2)	FF	Efficiency (%)
crystalline Si	4.0	0.706	42.2	82.8	24.7
crystalline GaAs	3.9	1.022	28.2	87.1	25.1
poly-Si	1.1	0.654	38.1	79.5	19.8
a-Si	1.0	0.887	19.4	74.1	12.7
$CuInGaSe_2$	1.0	0.669	35.7	77.0	18.4
CdTe	1.1	0.848	25.9	74.5	16.4

Eficienta maxima a celulei solare



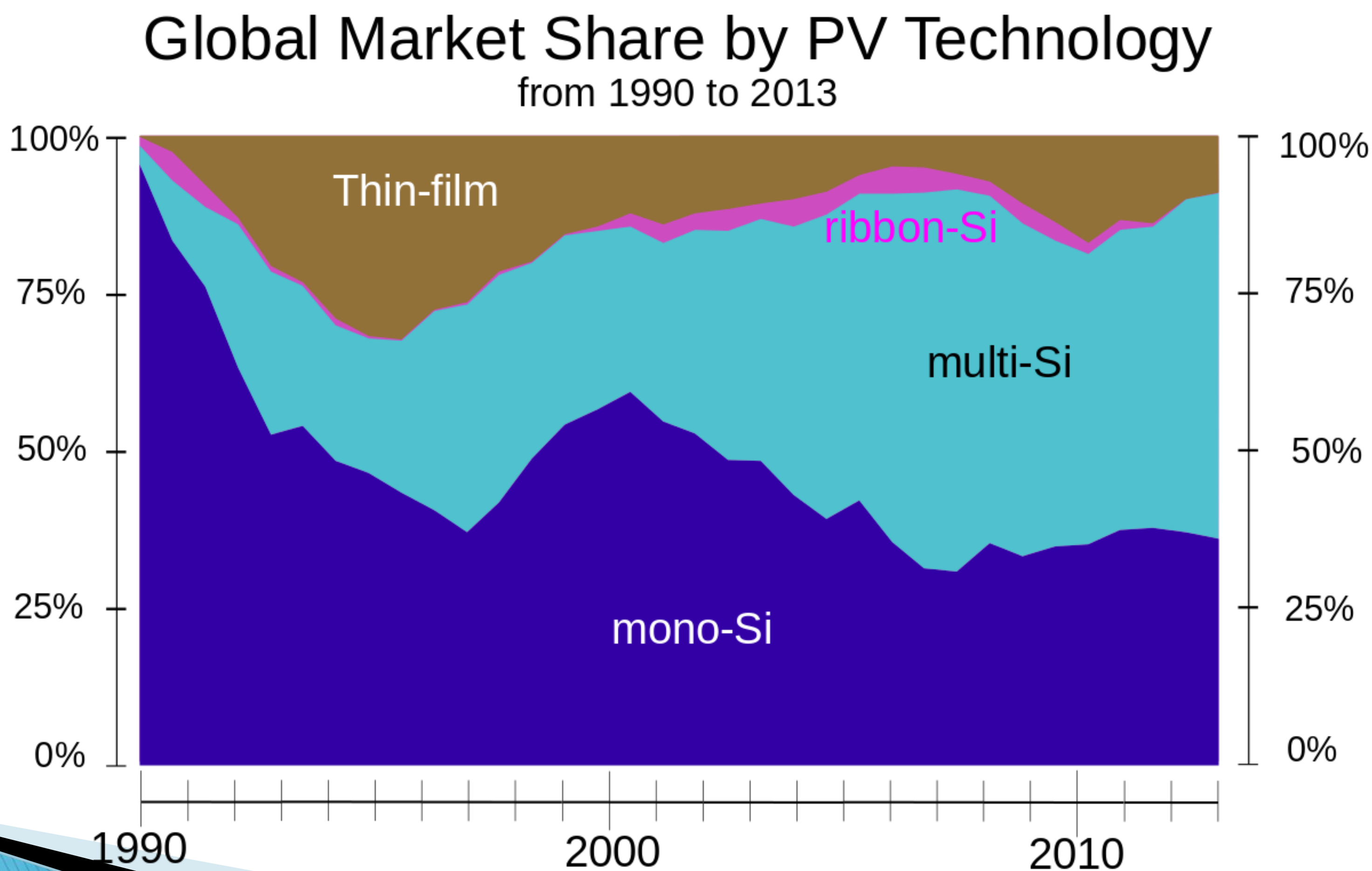
Dependenta de material

- materialele care ofera tensiuni mari au de obicei curenti mai mici
  - dependent de latimea benzii interzise



Realizari practice

- materialul preferat este Si



Tipic

80 WATT

POWERFUL PERFORMANCE. SHARP RELIABILITY.

POLY-CRYSTALLINE SILICON PHOTOVOLTAIC MODULE WITH 80W MAXIMUM POWER

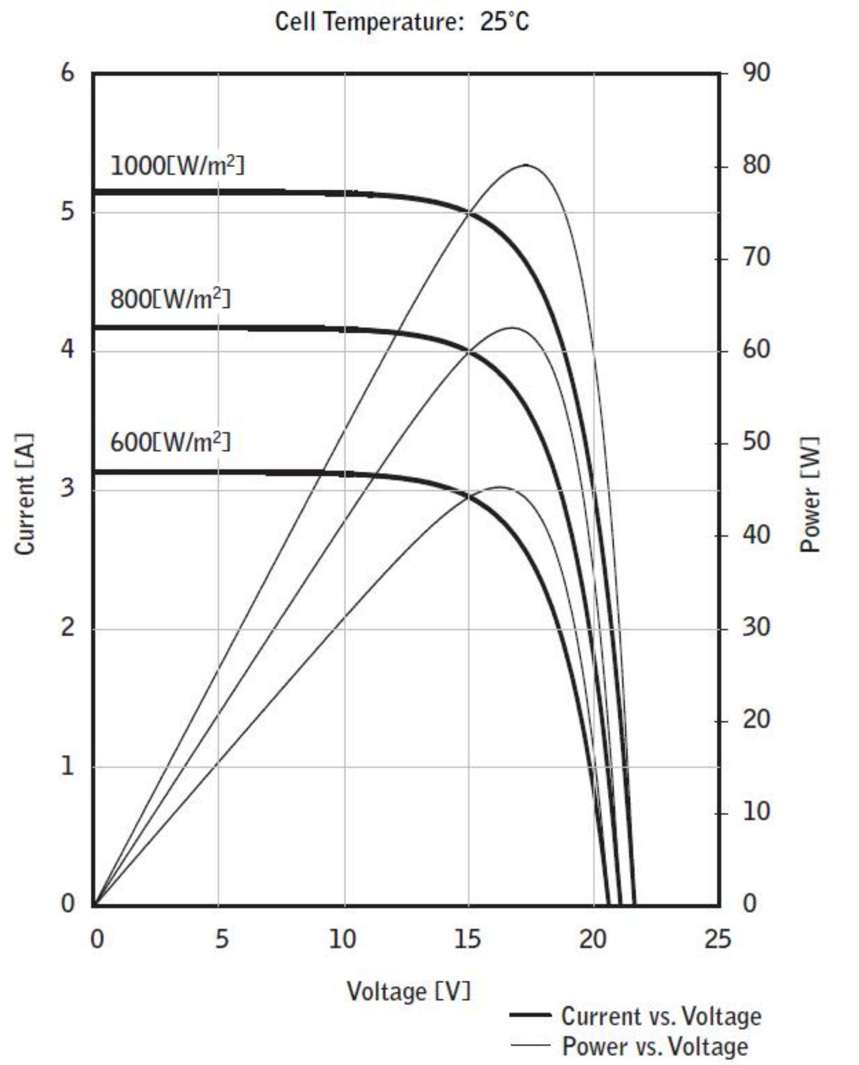
Sharp's NE-80EJEA photovoltaic modules offer industry-leading performance, durability, and reliability for a variety of electrical power requirements. Using breakthrough technology perfected by Sharp's 45 years of research and development, these modules incorporate an advanced surface texturing process to increase light absorption and improve efficiency. Common applications include cabins, solar power stations, pumps, beacons,

Tipic

ELECTRICAL CHARACTERISTICS

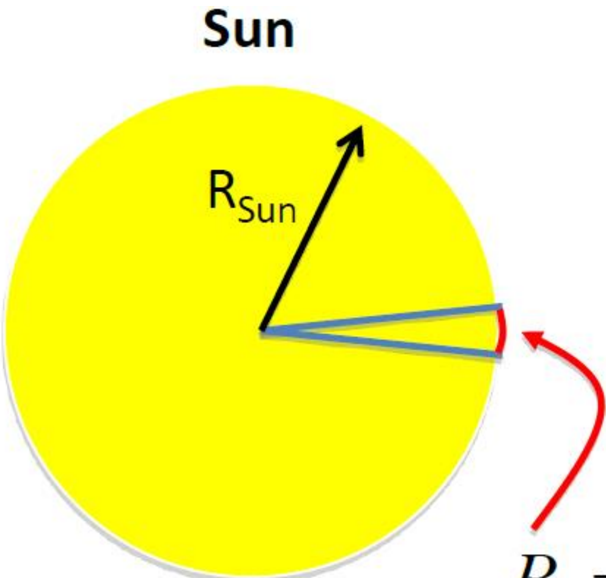
Cell	Poly-crystalline silicon
No. of Cells and Connections	36 in series
Open Circuit Voltage (Voc)	21.6V
Maximum Power Voltage (Vpm)	17.3V
Short Circuit Current (Isc)	5.16A
Maximum Power Current (Ipm)	4.63A
Maximum Power (Pmax)*	80W (+10% / -5%)
Module Efficiency (ηm)	12.40%
Maximum System Voltage	600VDC
Series Fuse Rating	10A
Type of Output Terminal	Junction Box

IV CURVES



Current, Power vs. Voltage Characteristics

Energia solara disponibila



$$P_o = \sigma \cdot T^4$$

Total Radiative Power of Sun (from Stefan-Boltzman law, T =5762±50K)

Power radiated per unit area 6.250×10^7 W/m^2

Assumes Sun is a “black body.”

Energia solara disponibila

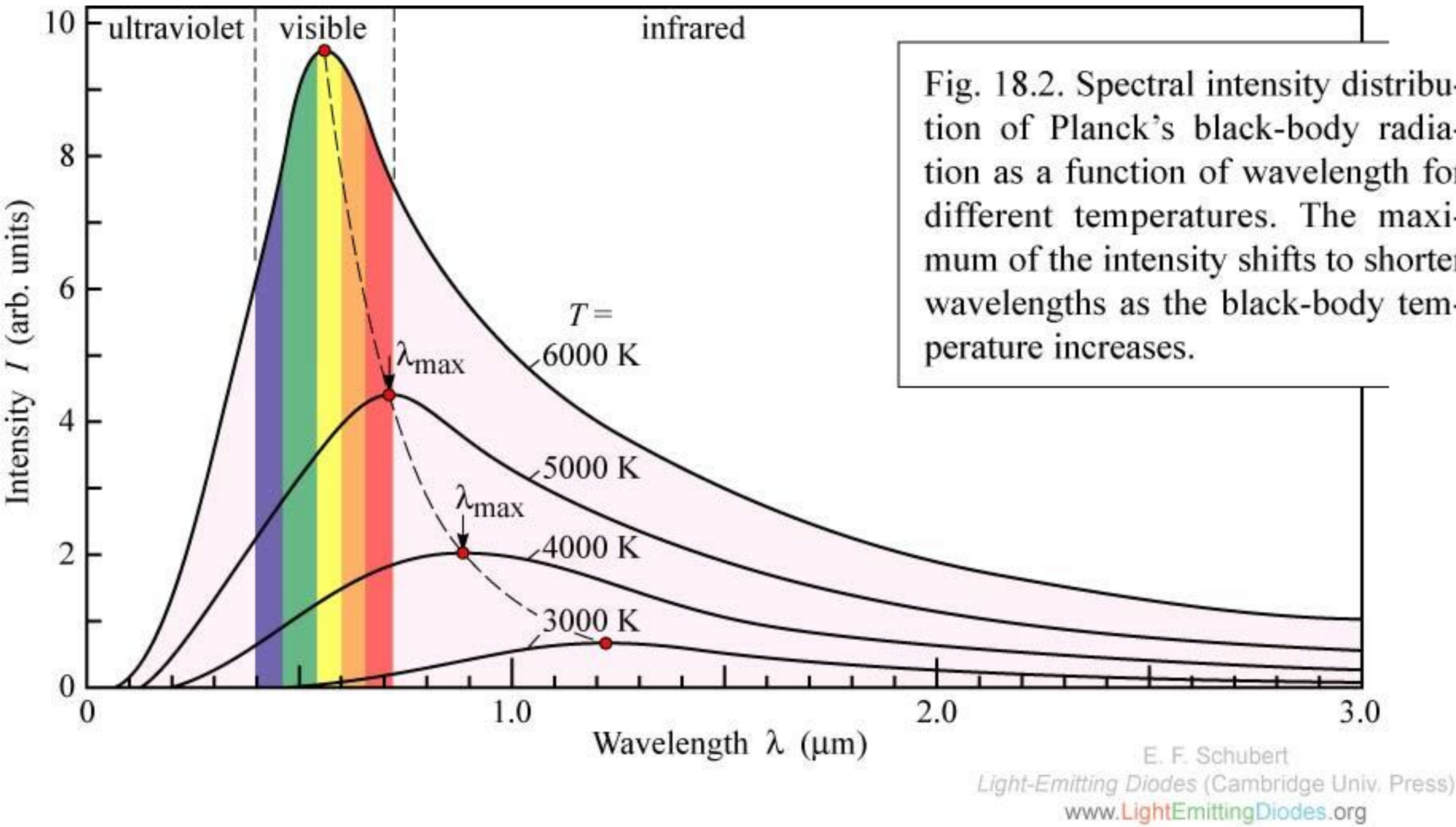
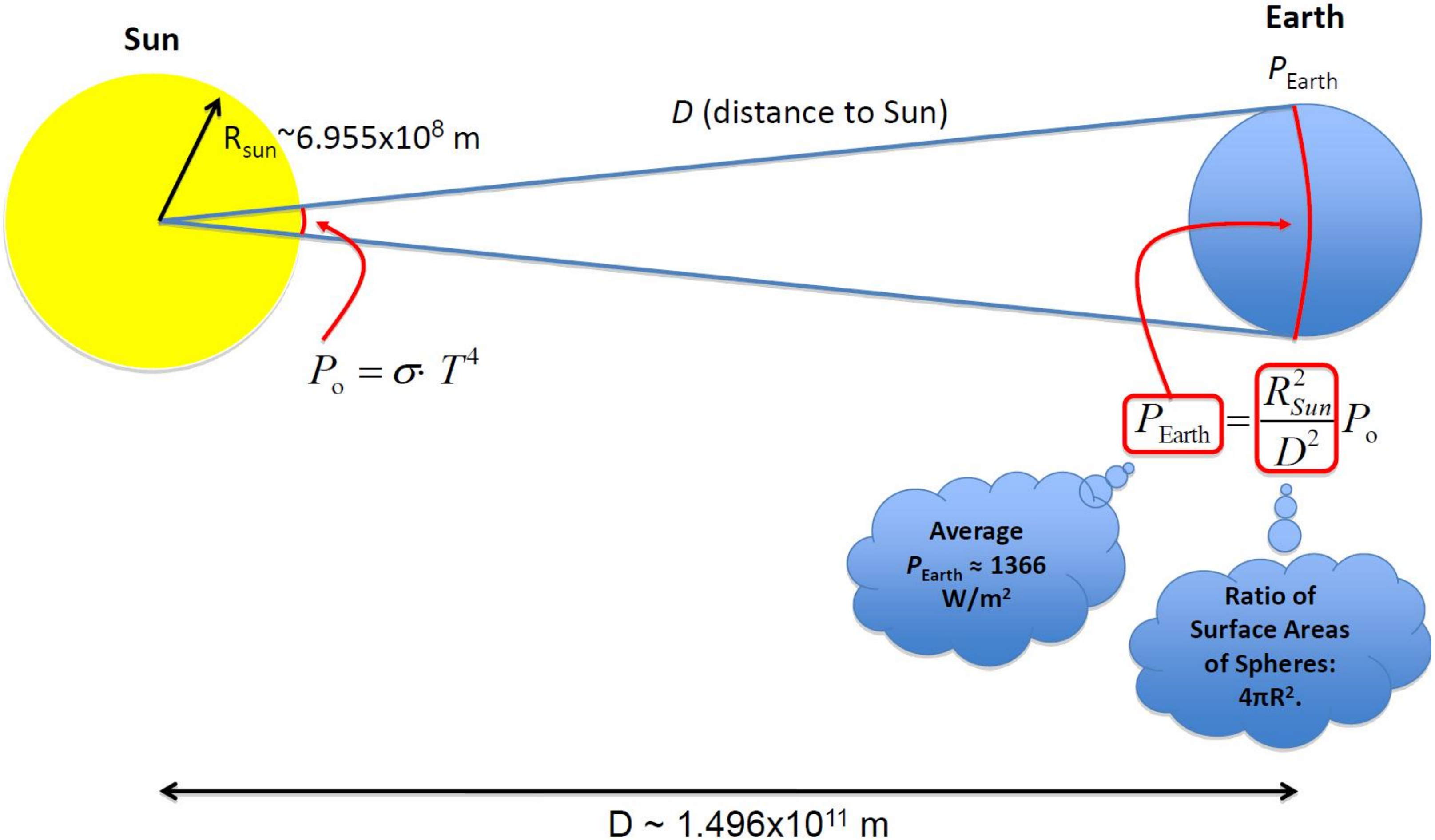


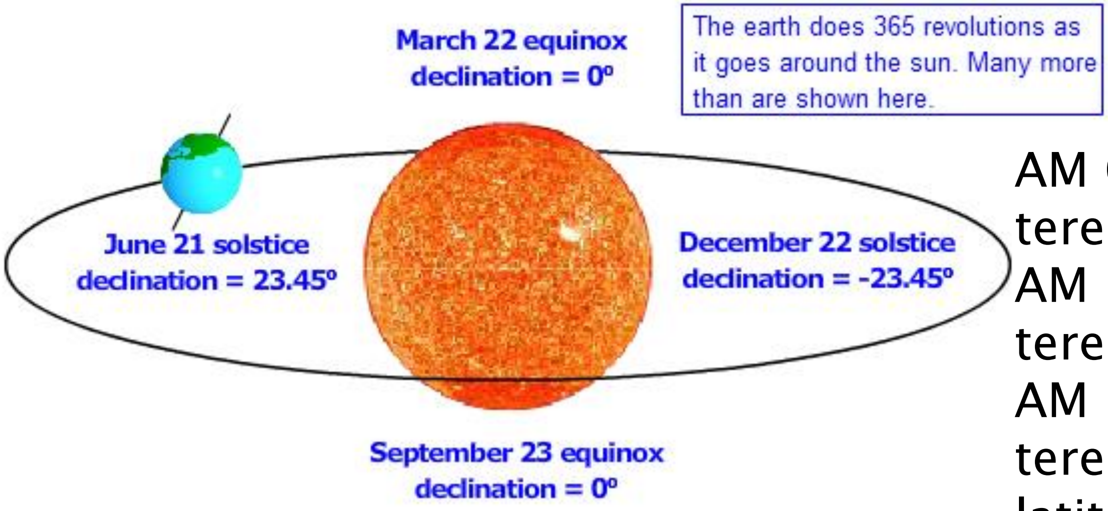
Fig. 18.2. Spectral intensity distribution of Planck's black-body radiation as a function of wavelength for different temperatures. The maximum of the intensity shifts to shorter wavelengths as the black-body temperature increases.

Energia solara disponibila

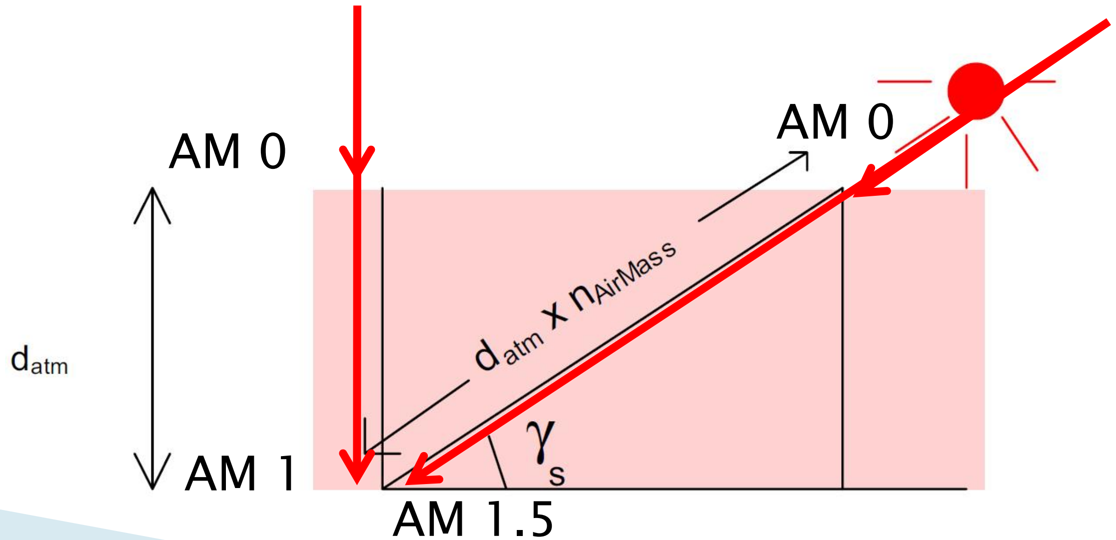


Energia receptionata pe toata suprafata Pamantului intr-**o ora** mai mare decat toata energia consumata de intreaga populatie intr-**un an**

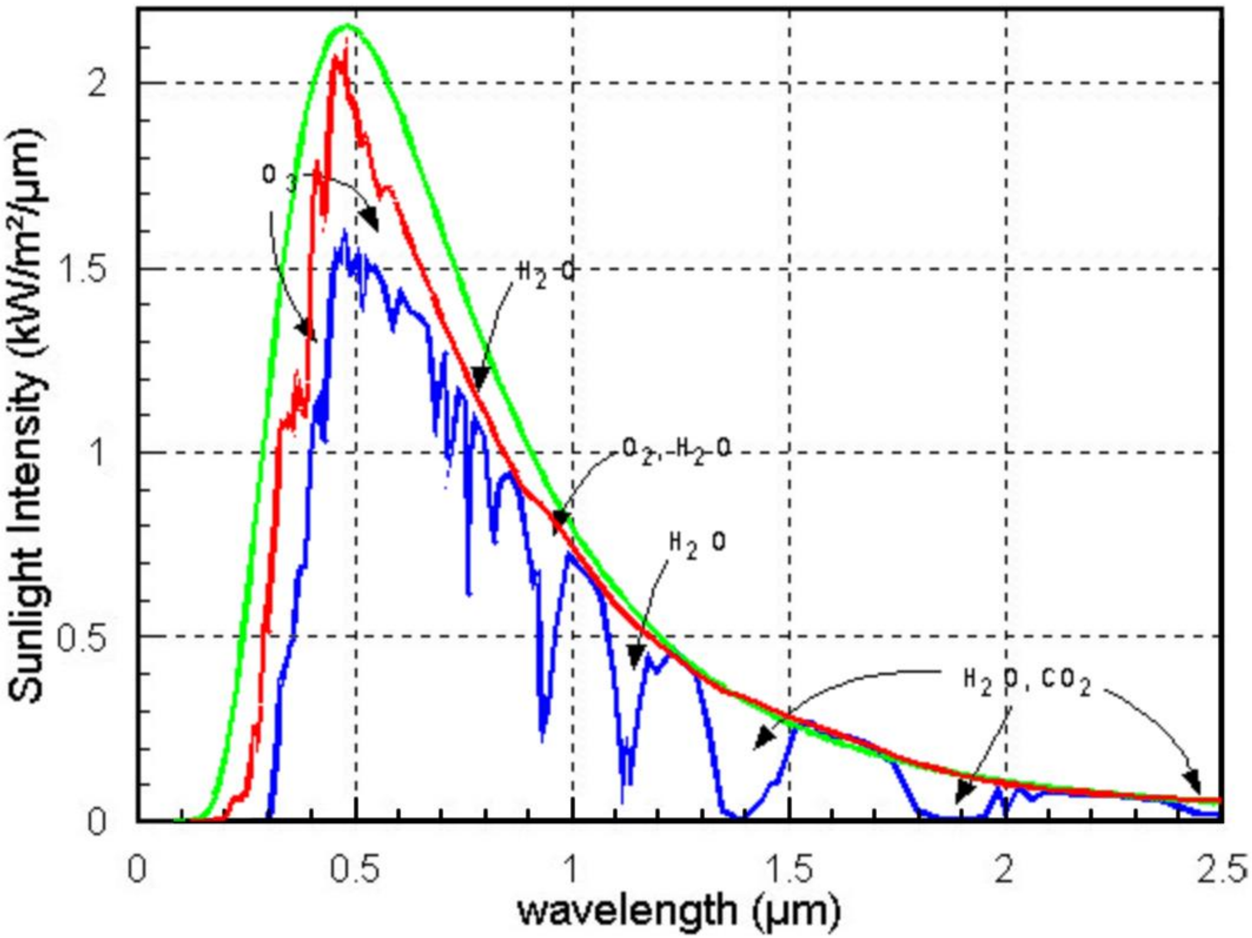
Energia solara disponibila



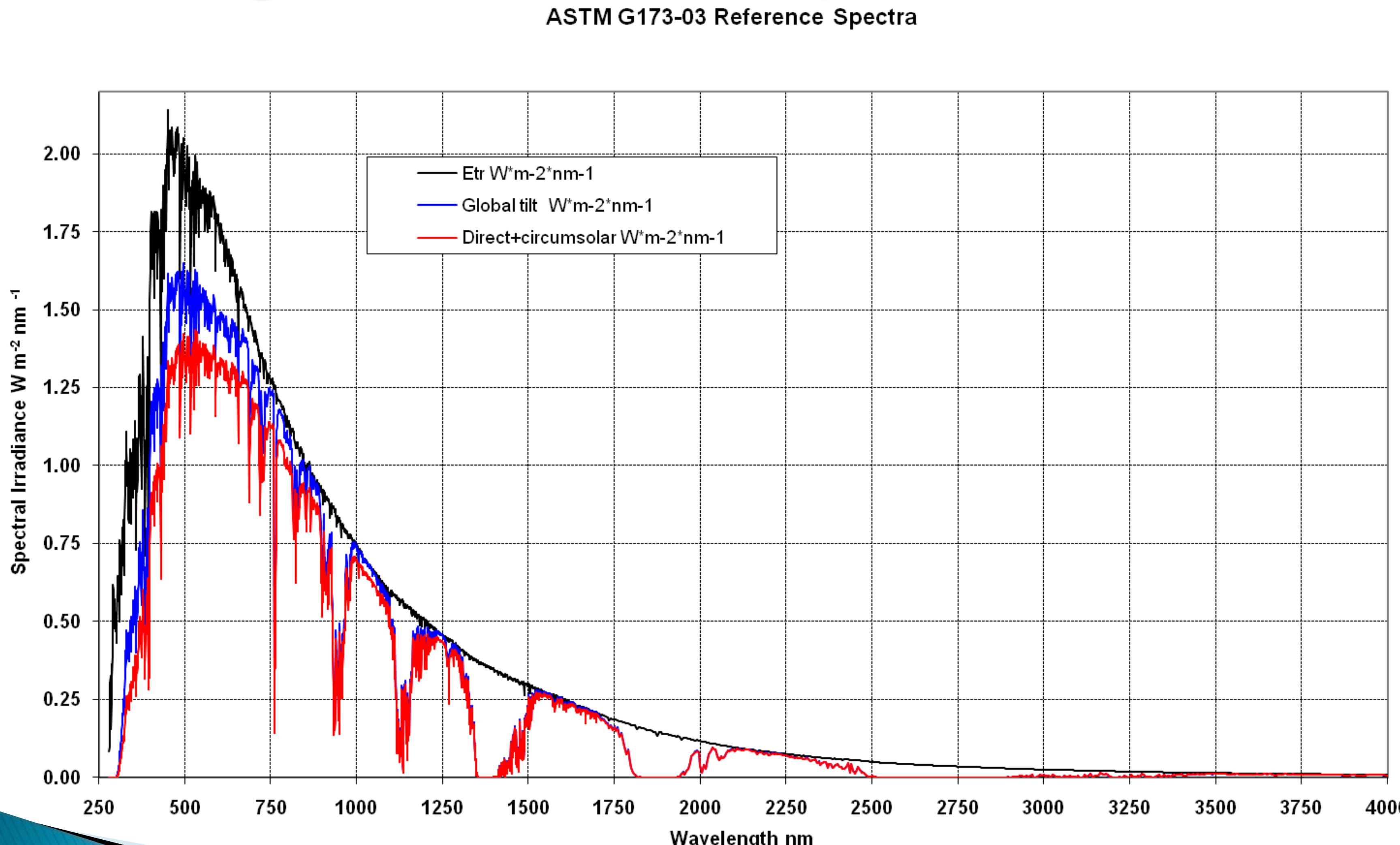
AM 0 = radiatia in afara atmosferei terestre
AM 1 = radiatia la suprafata terestra, incidenta normala
AM 1.5 = radiatia la suprafata terestra, incidenta corespunzatoare latitudinii de 48° (**standard**)



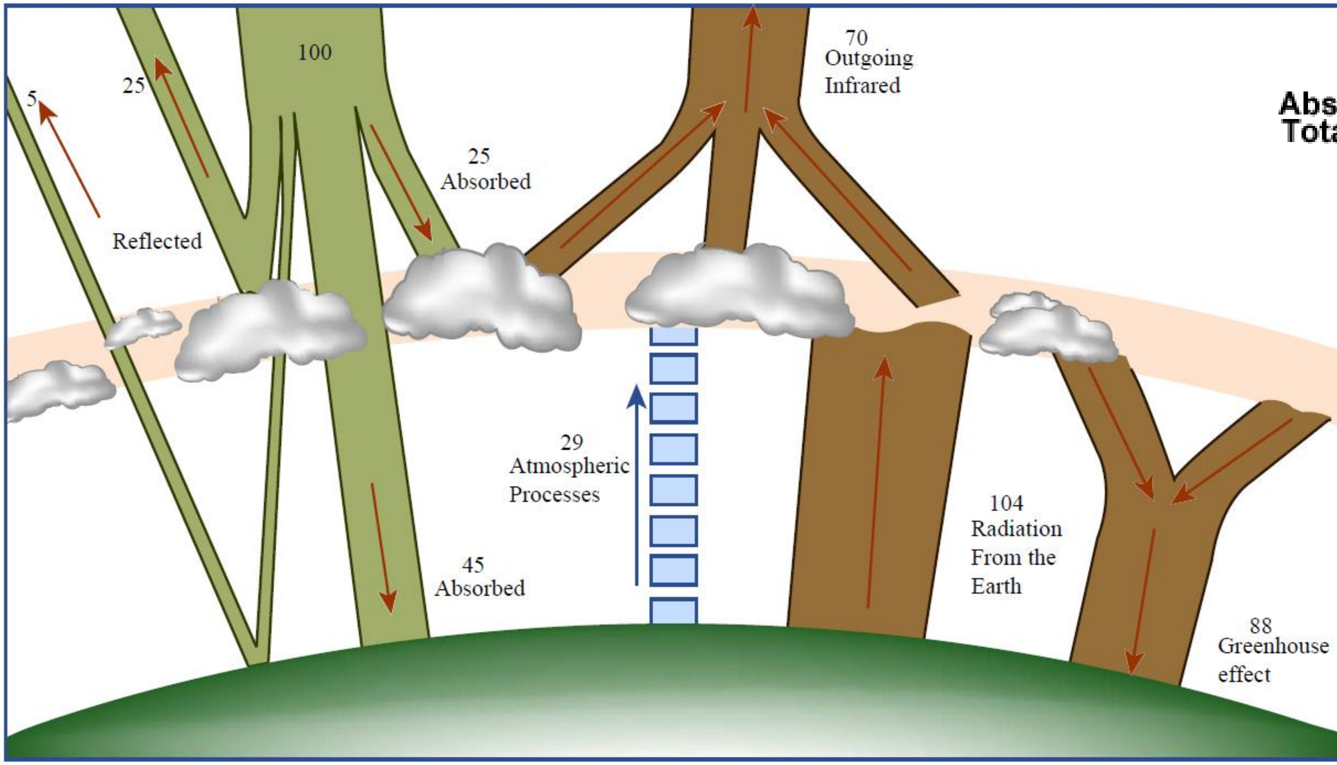
Energia solara disponibila



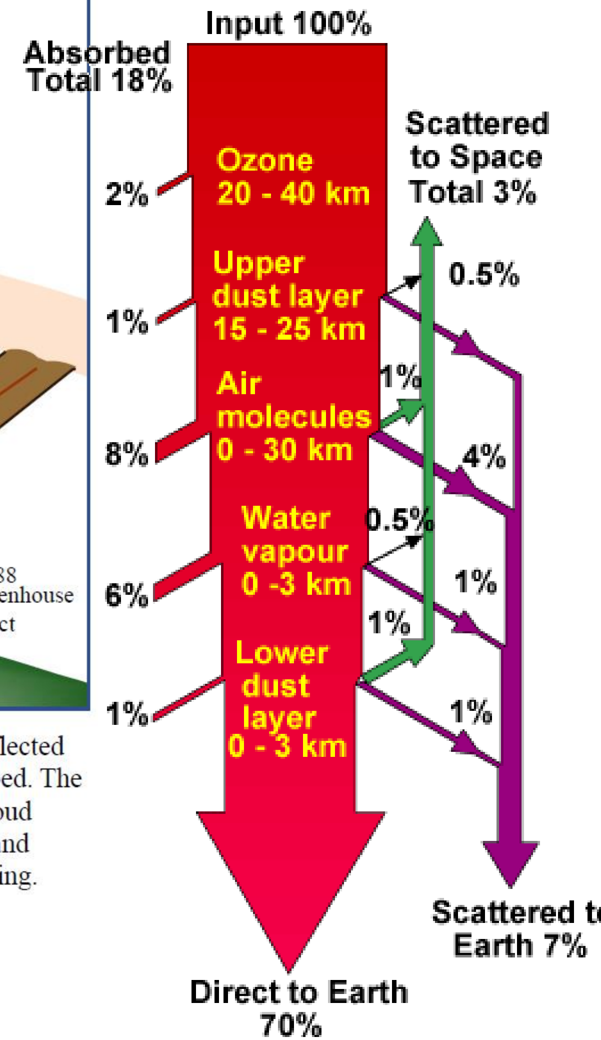
Energia solara disponibila



Energia solara disponibila



Heat trapping in the atmosphere dominates the earth's energy balance. Some 30% of incoming solar energy is reflected (left), either from clouds and particles in the atmosphere or from the earth's surface; the remaining 70% is absorbed. The absorbed energy is reemitted at infrared wavelengths by the atmosphere (which is also heated by updrafts and cloud formation) and by the surface. Because most of the surface radiation is trapped by clouds and greenhouse gases and returned to the earth, the surface is currently about 33 degrees Celsius warmer than it would be without the trapping.



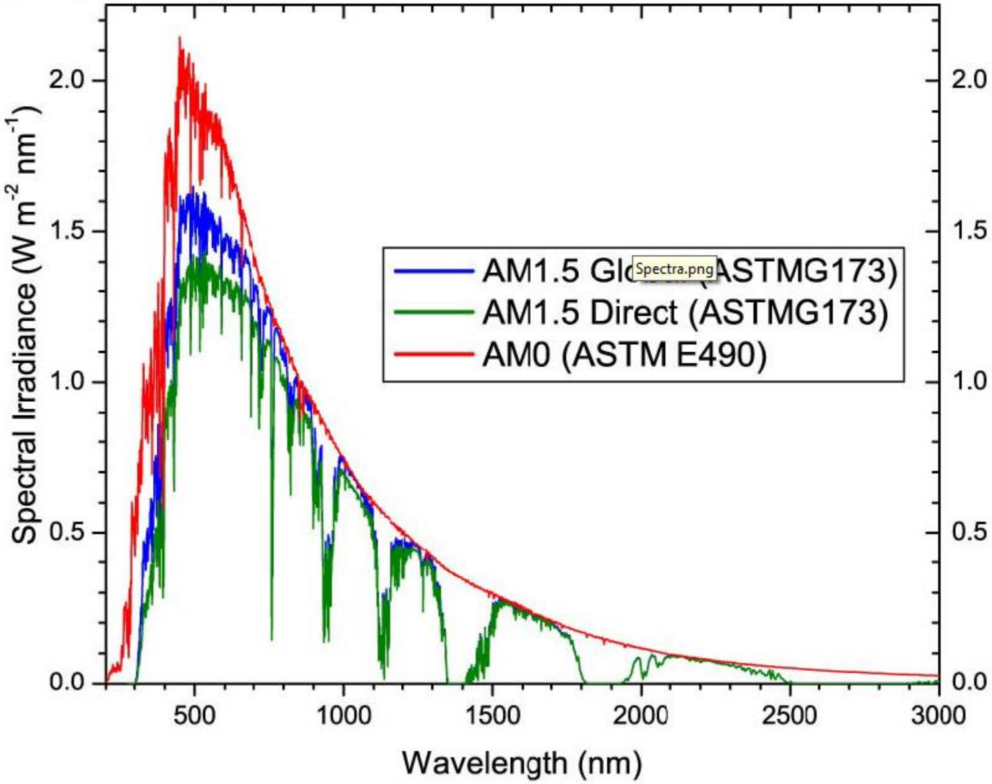
Energia solara disponibila

SOLAR SPECTRUM

AM1.5 Global: Used for testing of Flat Panels (Integrated power intensity: 1000 W/m^2)

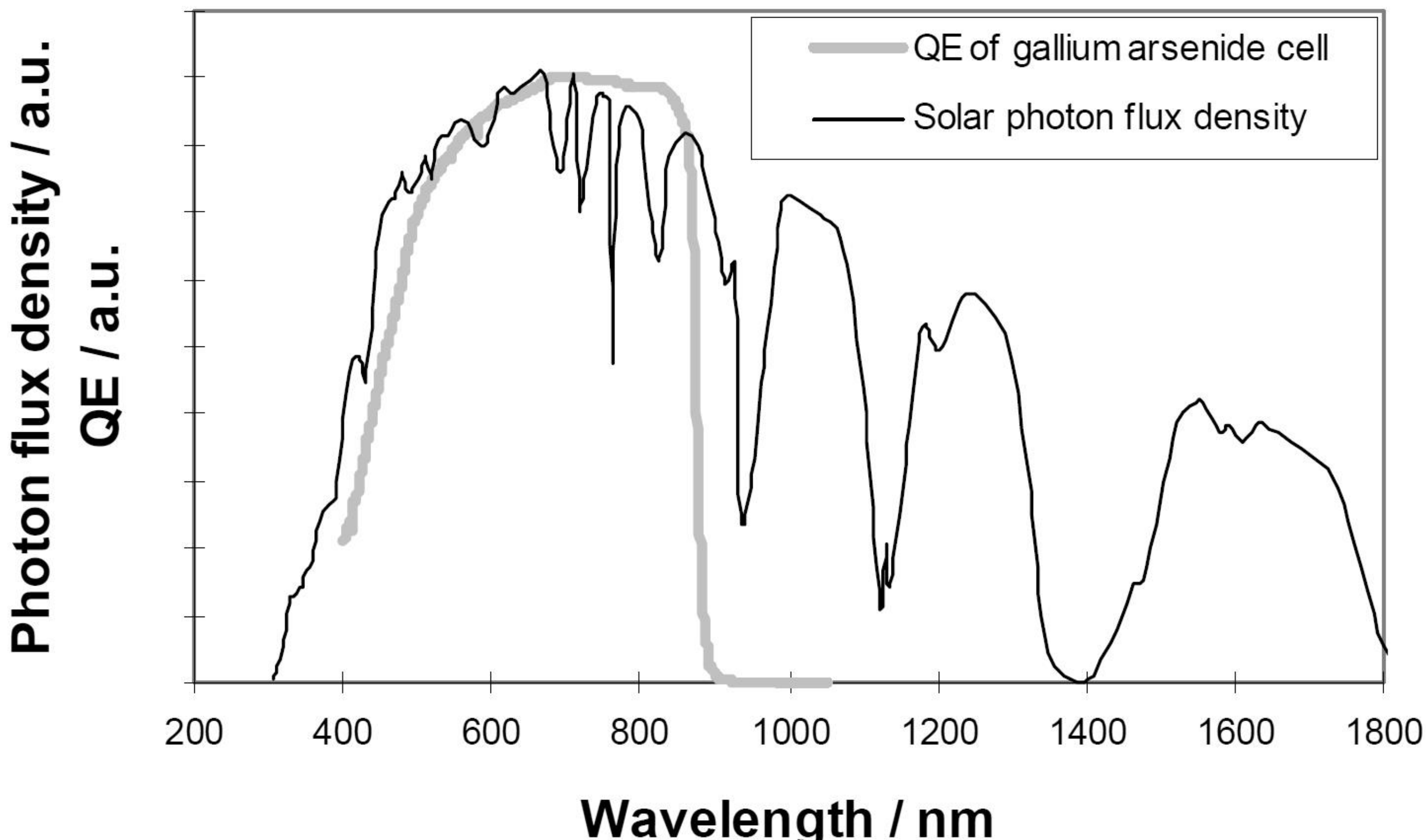
AM1.5 Direct: Used for testing of concentrators (900 W/m^2)

AM0: Outer space (1366 W/m^2)

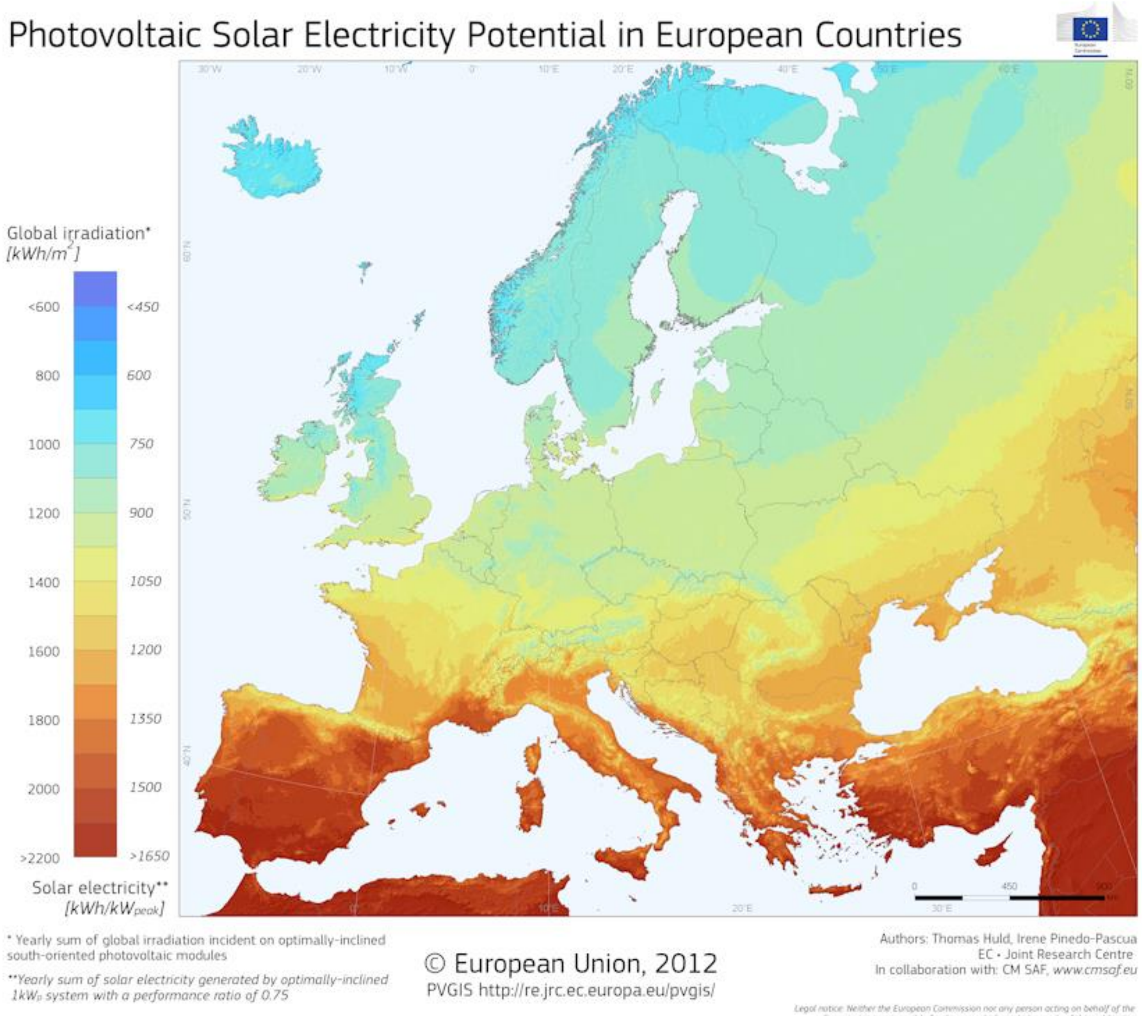


Motivatie eficienta limitata

- Toate materialele utilizate au o banda care acopera **doar** partial spectrul solar (ex. GaAs)



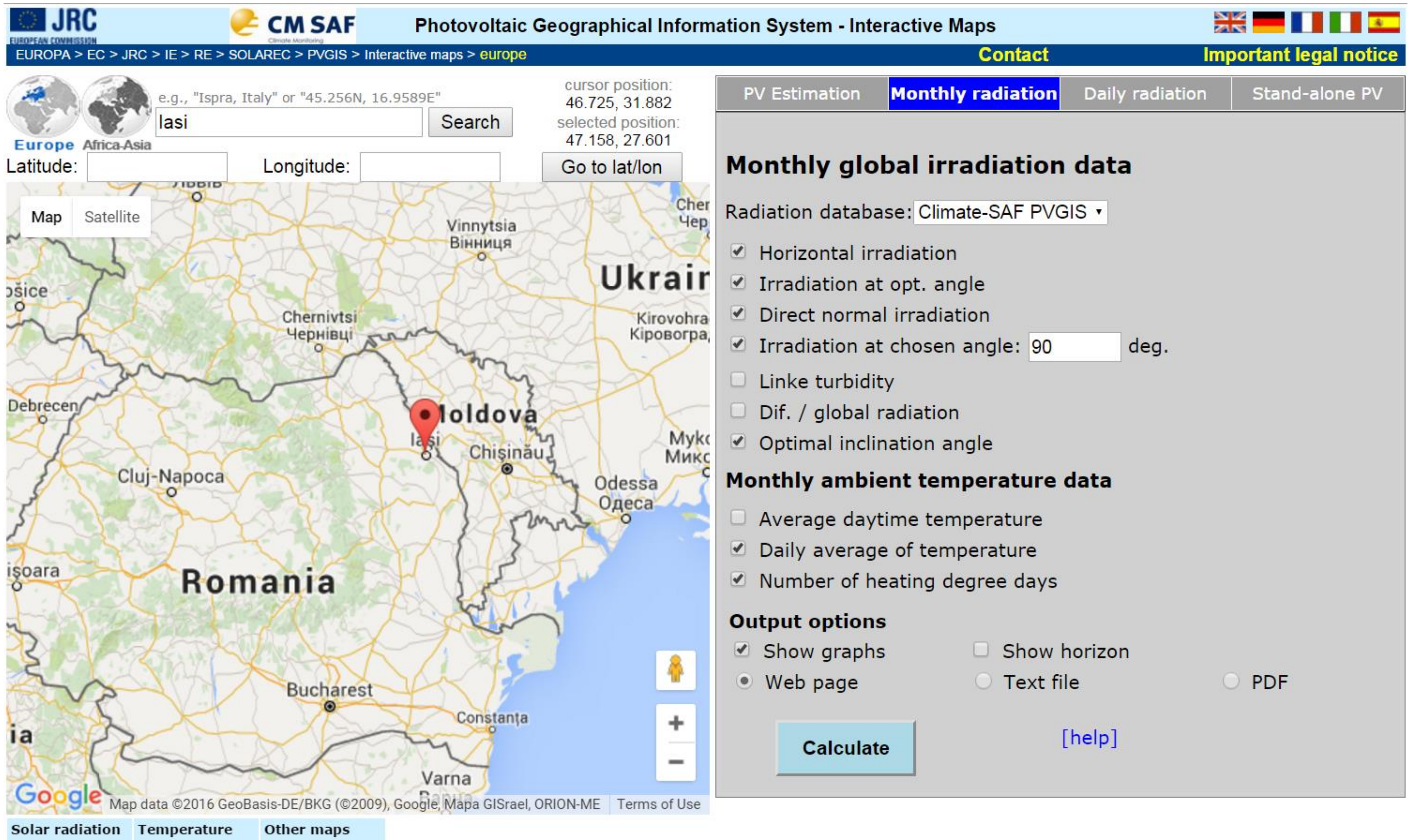
Energia solara disponibila



http://re.jrc.ec.europa.eu/pvgis/

Energia solara disponibila

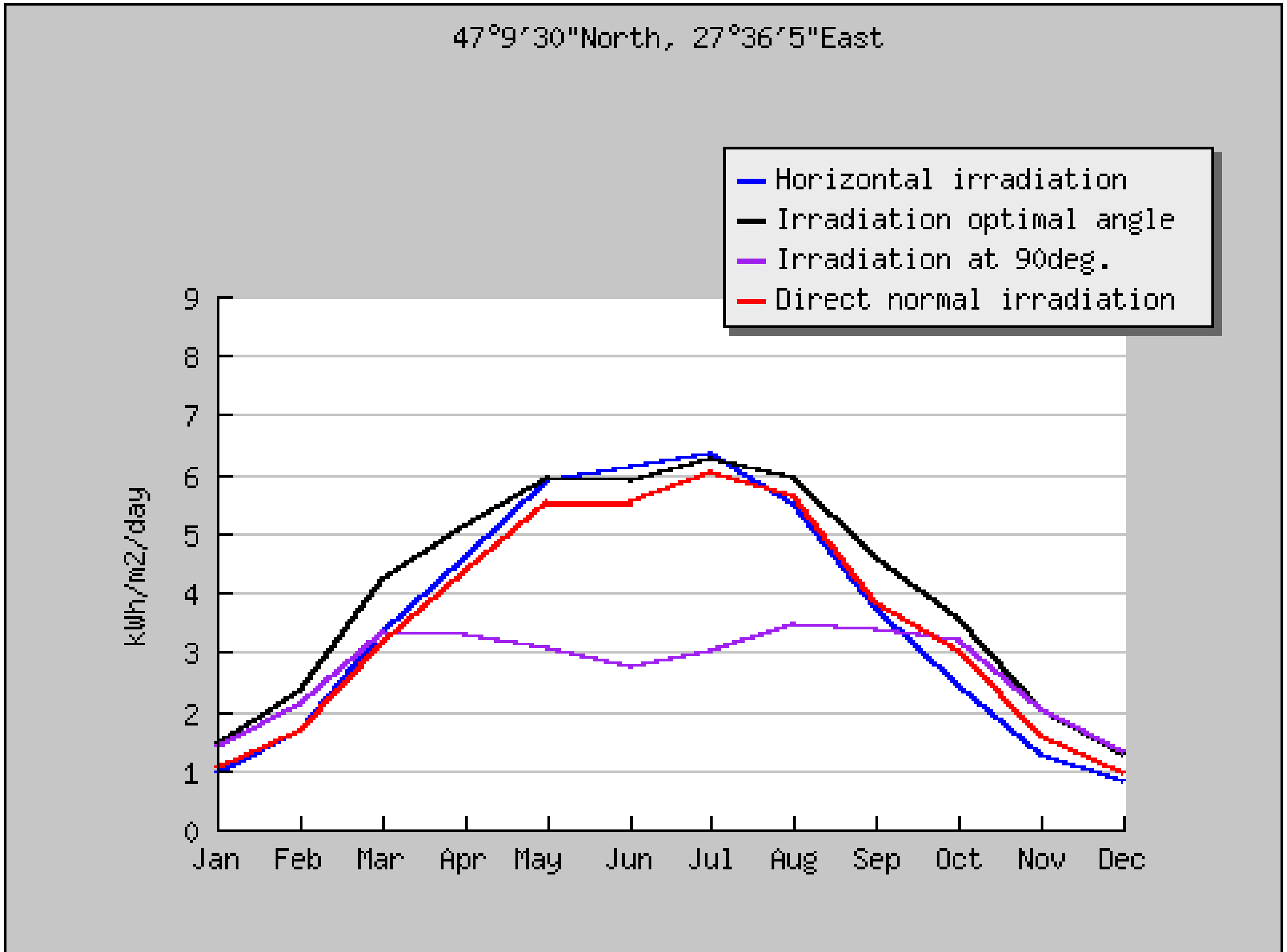
Energia solara disponibila



Photovoltaic Geographical Information System (PVGIS)

http://re.jrc.ec.europa.eu/pvgis/

Energia solara disponibila – Iasi



Unghi optim de inclinare

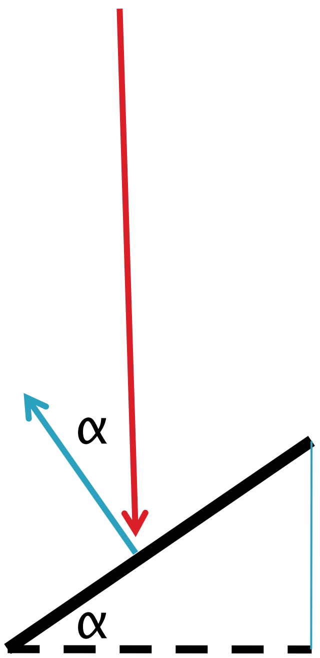
- Puterea optica depinde de fluxul energetic al luminii incidente si suprafata celulei
  - la **incidenta normala**

$$P_o = S \cdot \int_0^{\infty} \Phi_e(\lambda) d\lambda$$

  - la **incidenta oarecare**

$$\Phi_e(\lambda) = \int_{\Sigma} \vec{S} \cdot \vec{n} dA = |S| \cdot A \cdot \cos\alpha$$

$$\vec{S} = \vec{E} \times \vec{H}$$

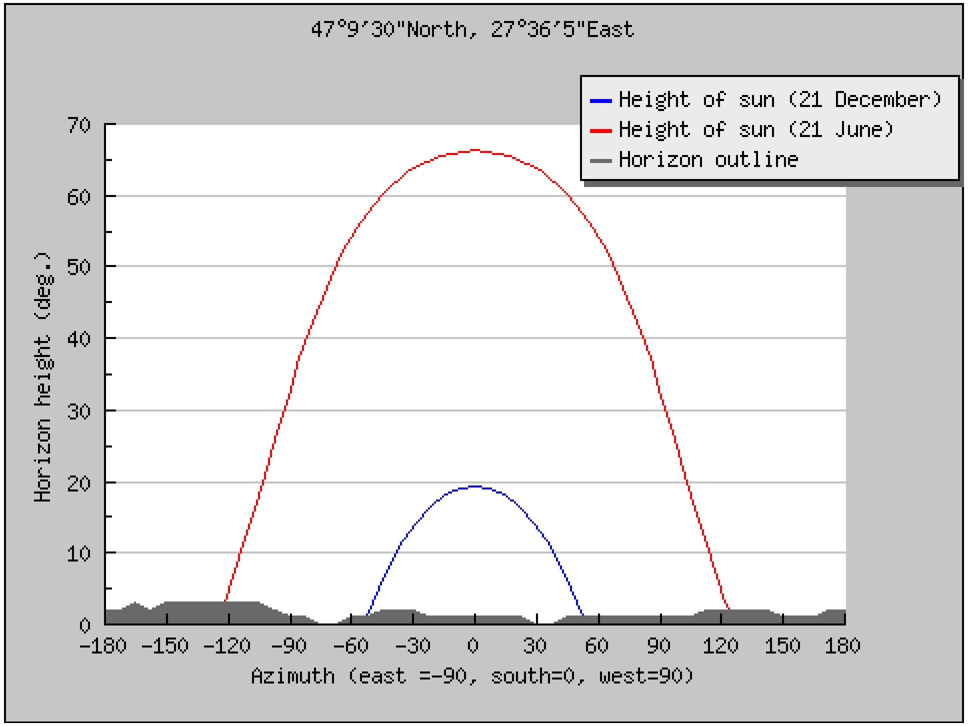


Unghi optim de inclinare

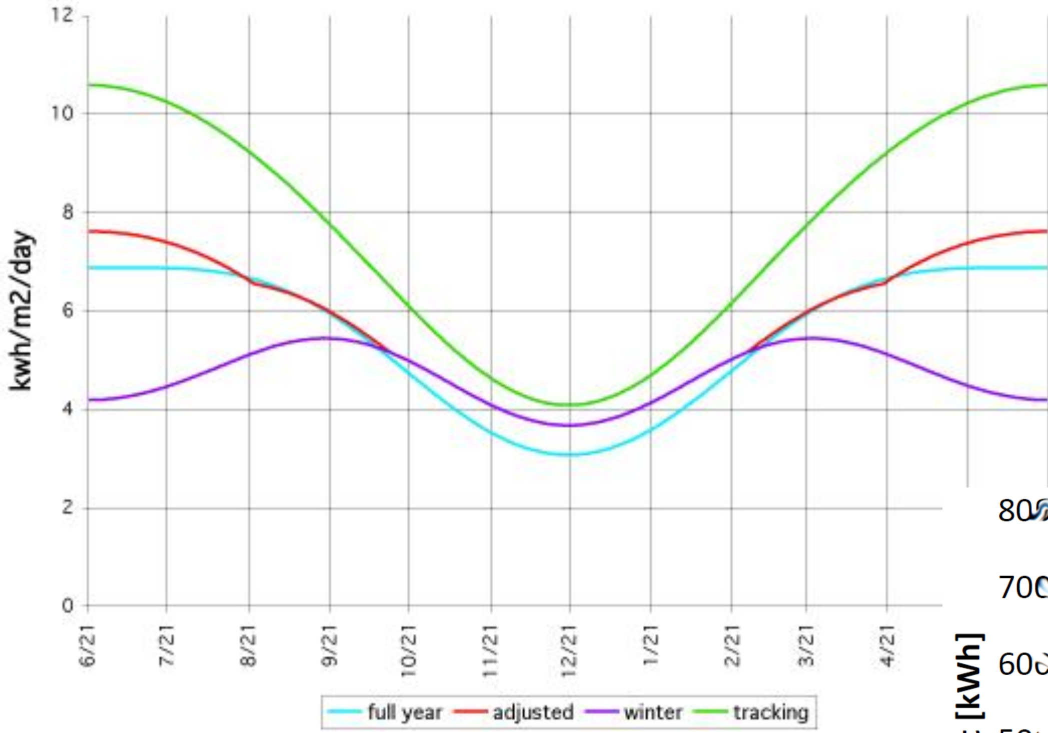
- Pozitia soarelui este diferita
  - in functie de ora
  - in functie de anotimp

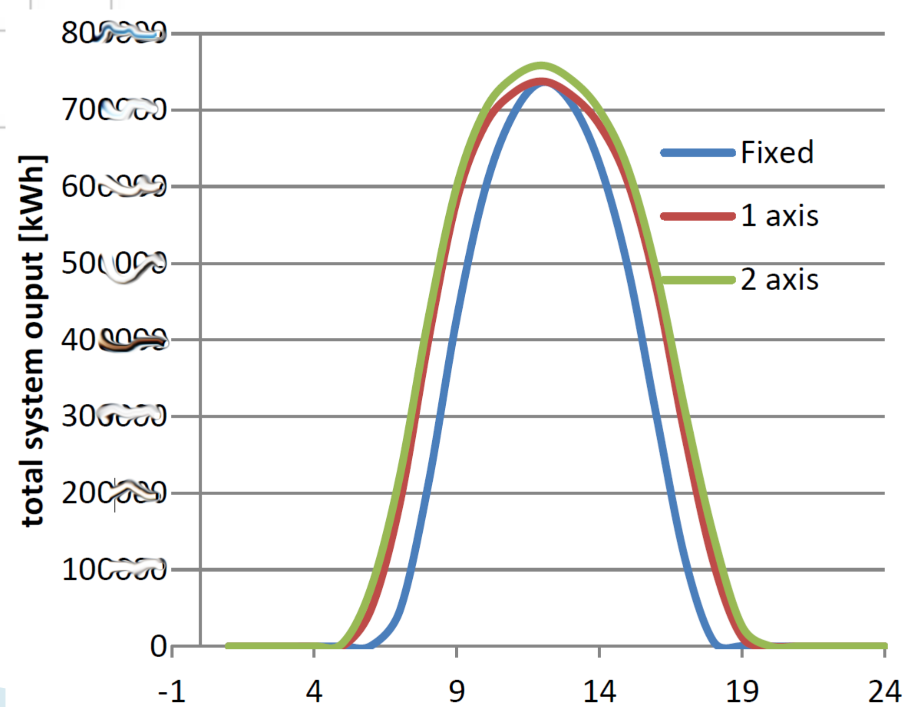
Sisteme de urmarire

- Sisteme motorizate de urmarire a soarelui
  - o axa
  - doua axe
- Reglaj
  - fix (optim an)
  - doua pozitii (anotimp)



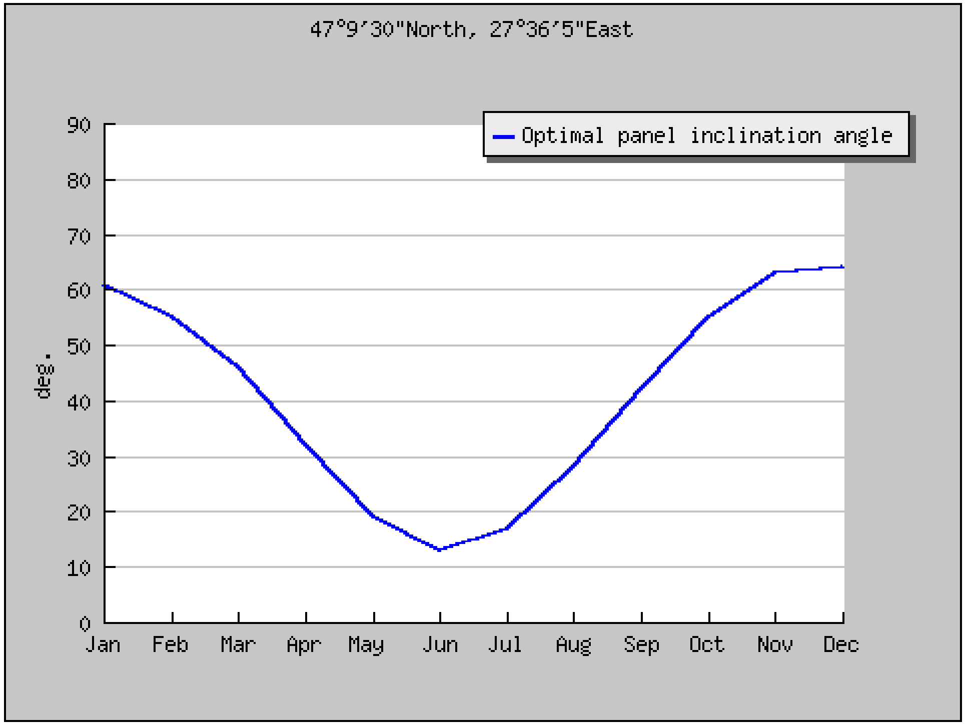
Sisteme de urmarire



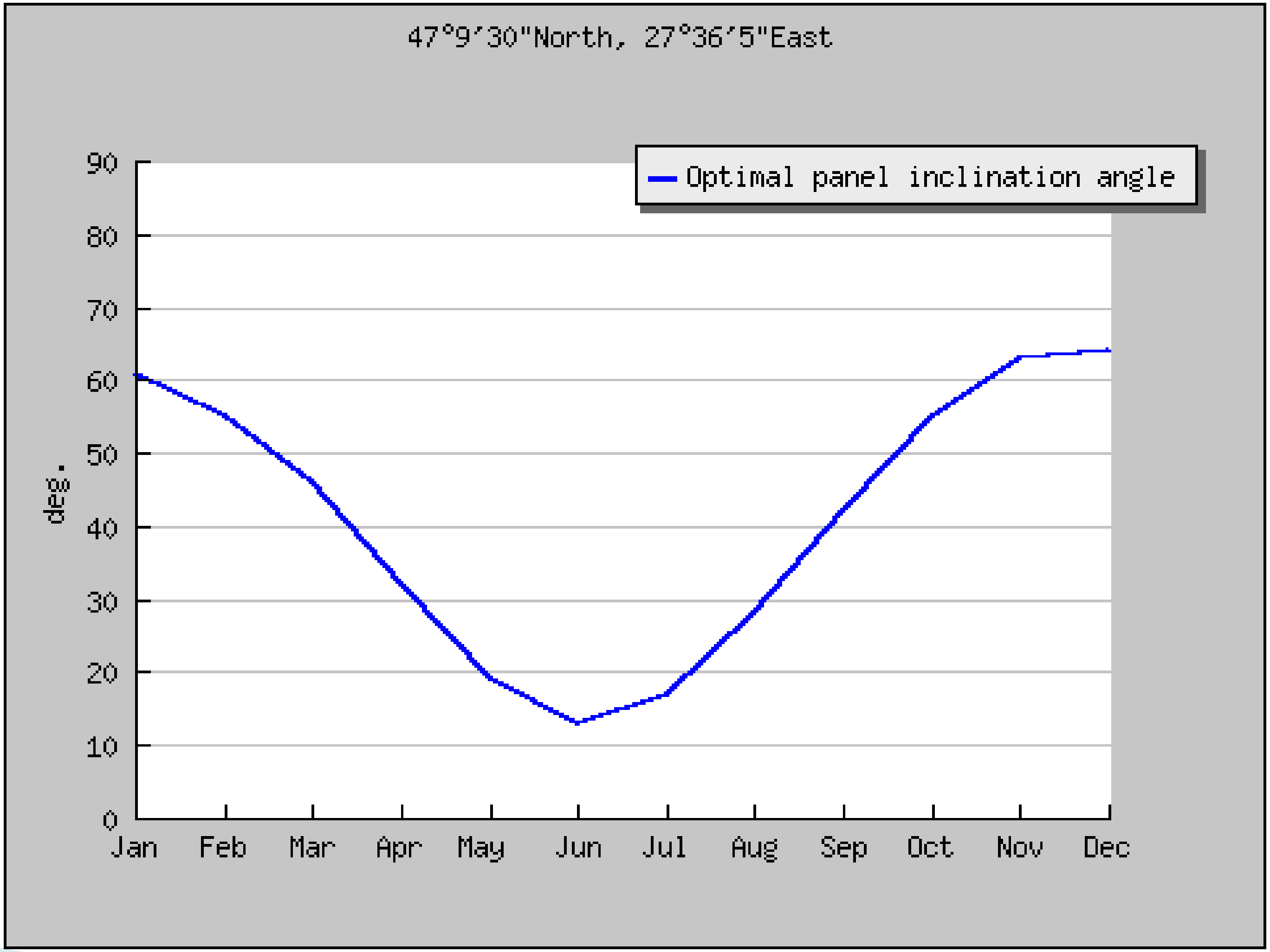


Unghi optim de inclinare

- Panourile se orienteaza spre sud (**geografic**)
- Inclinarea pe verticala se poate calcula din considerente
  - geometrice
  - astronomice



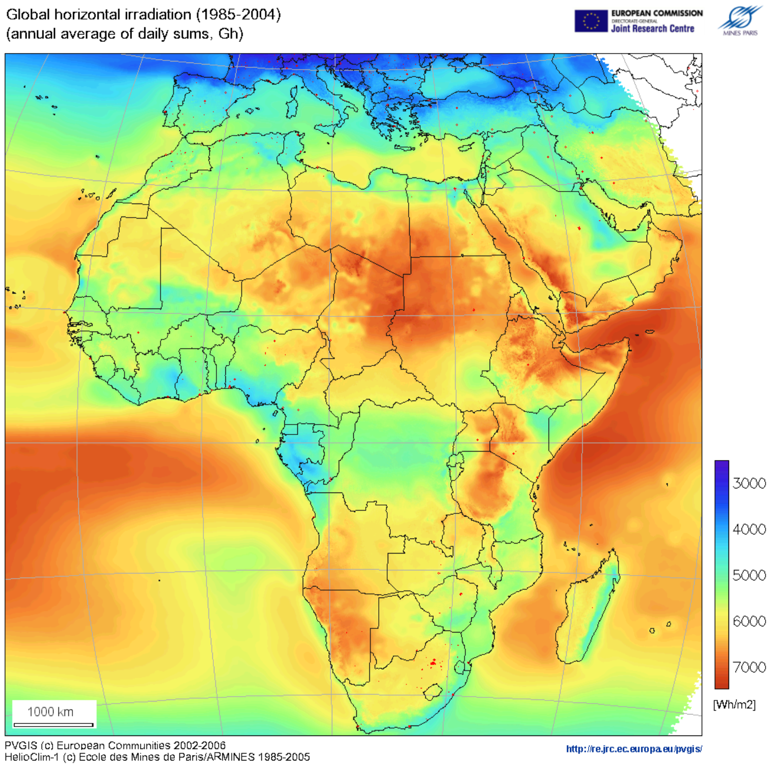
Iasi

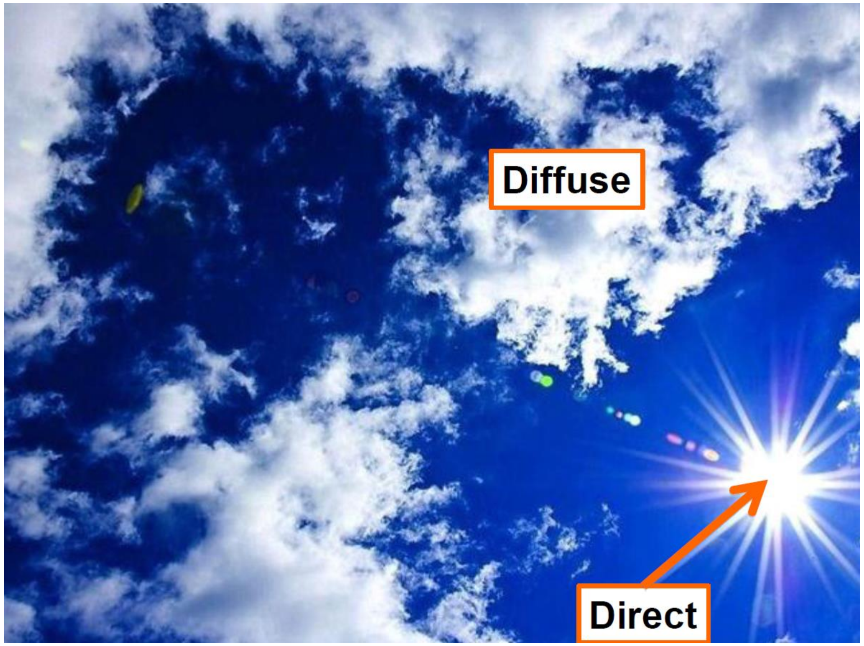


47°9′30"North, 27°36′5"East
Optimal panel inclination angle
deg.
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

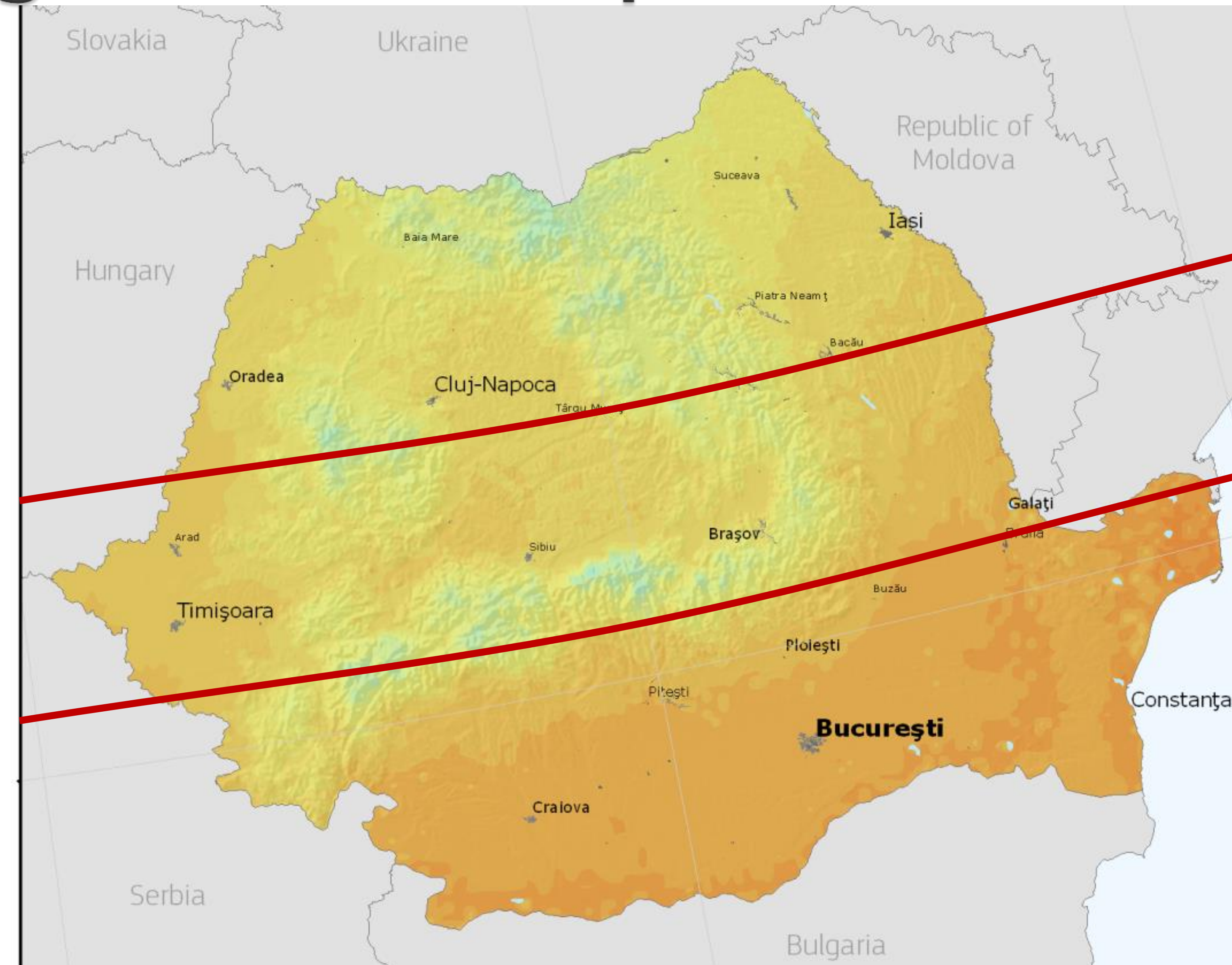
Tip de sistem de urmarire

- depinde de tipul de sistem solar
  - cu concentrare
  - fara concentrare
- depinde de conditii meteorologice





Energia solara disponibila



Iasi

Month	H_h	H_{opt}	H(90)	DNI	I_{opt}	T_{24h}
Jan	956	1440	1410	1020	61	-2.5
Feb	1680	2350	2130	1670	55	-1.4
Mar	3310	4210	3330	3150	46	4.0
Apr	4580	5150	3280	4380	32	10.6
May	5900	5960	3070	5530	19	16.7
Jun	6140	5900	2760	5530	13	20.0
Jul	6320	6240	3010	6010	17	22.3
Aug	5470	5960	3460	5630	28	21.4
Sep	3720	4600	3390	3820	42	16.1
Oct	2450	3570	3210	3000	55	10.2
Nov	1260	2000	2010	1600	63	5.5
Dec	802	1280	1310	959	64	-0.8
Year	3560	4070	2700	3540	35	10.2

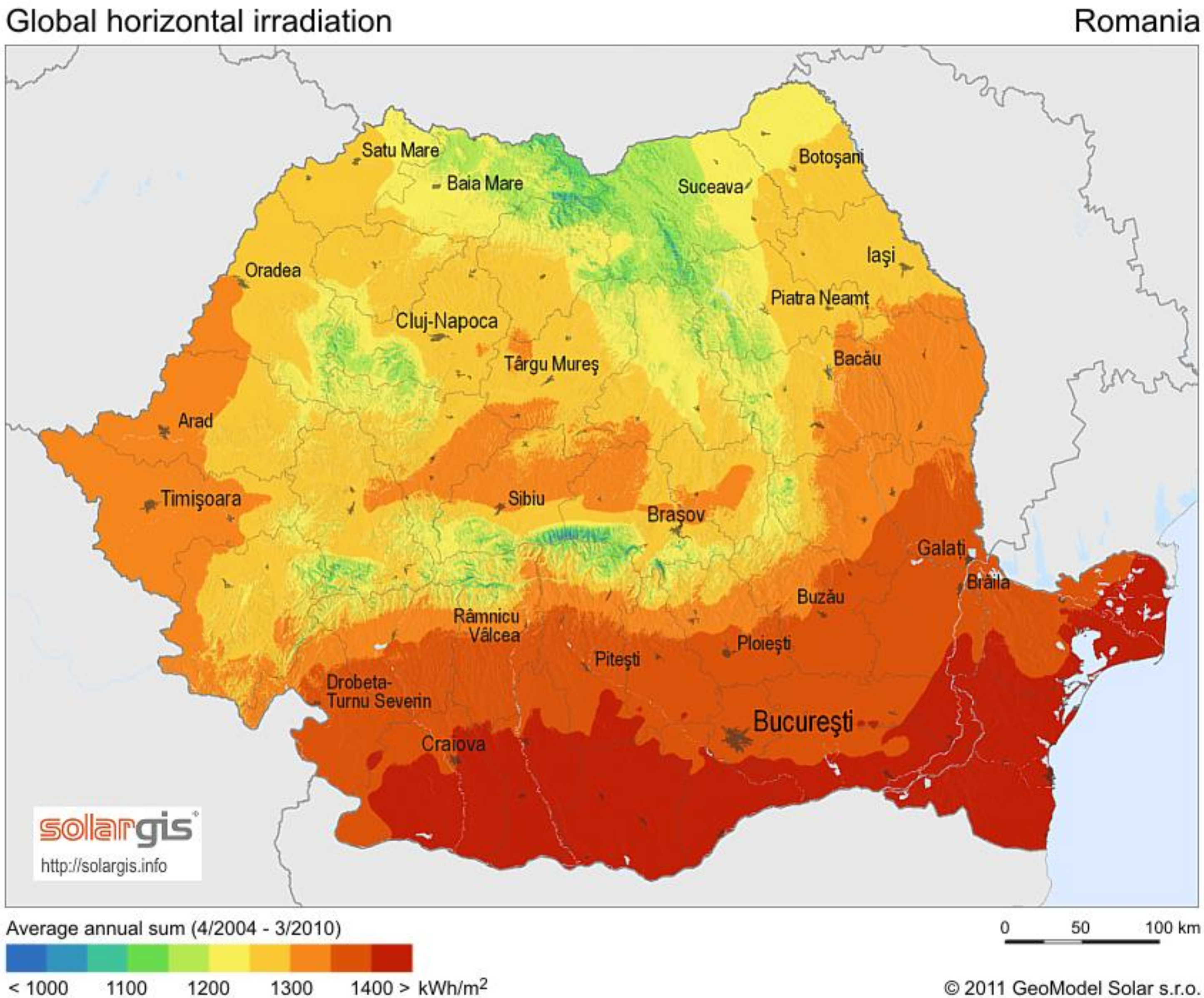
Iasi

http://re.jrc.ec.europa.eu/pvgis/

Month	H_h	H_{opt}	H(90)	DNI	I_{opt}	T_{24h}
Jan	956	1440	1410	1020	61	-2.5
Feb	1680	2350	2130	1670	55	-1.4
Mar	3310	4210	3330	3150	46	4.0
Apr	4580	5150	3280	4380	32	10.6
May	5900	5960	3070	5530	19	16.7
Jun	6140	5900	2760	5530	13	20.0
Jul	6320	6240	3010	6010	17	22.3
Aug	5470	5960	3460	5630	28	21.4
Sep	3720	4600	3390	3820	42	16.1
Oct	2450	3570	3210	3000	55	10.2
Nov	1260	2000	2010	1600	63	5.5
Dec	802	1280	1310	959	64	-0.8
Year	3560	4070	2700	3540	35	10.2

H_h: Irradiation on horizontal plane (Wh/m²/day)
H_{opt}: Irradiation on optimally inclined plane (Wh/m²/day)
H(90): Irradiation on plane at angle: 90deg. (Wh/m²/day)
DNI: Direct normal irradiation (Wh/m²/day)
I_{opt}: Optimal inclination (deg.)
T_{24h}: 24 hour average of temperature (°C)

Romania

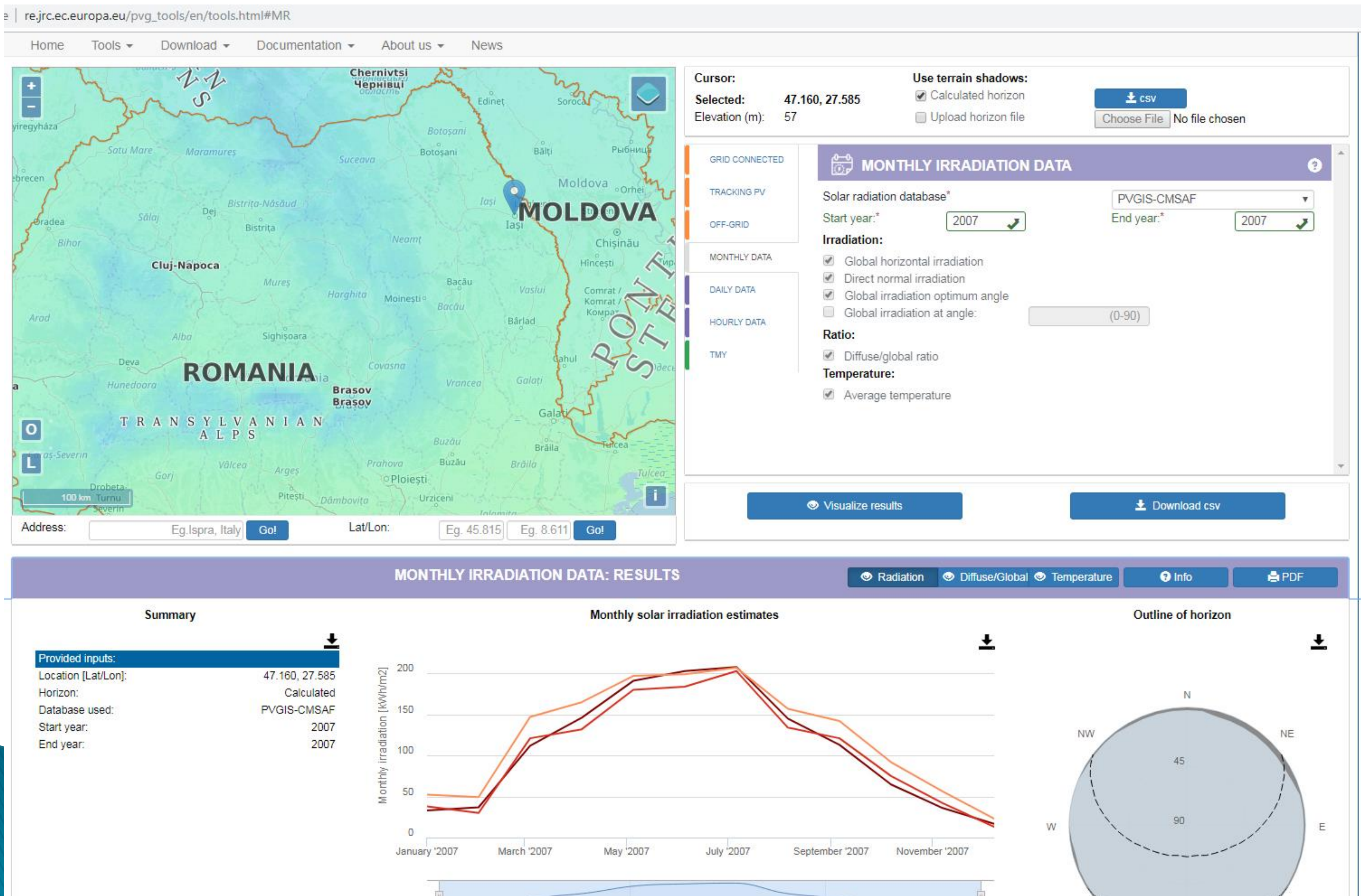

Global horizontal irradiation
Romania
Satu Mare
Baia Mare
Suceava
Botoşani
Iaşi
Oradea
Piatra Neamţ
Cluj-Napoca
Târgu Mureş
Bacău
Arad
Timişoara
Sibiu
Braşov
Galaţi
Brăila
Buzău
Râmnicu Vâlcea
Piteşti
Ploieşti
Drobeta-Turnu Severin
Bucureşti
Craiova
solargis
http://solargis.info
Average annual sum (4/2004 - 3/2010)
< 1000
1100
1200
1300
1400 > kWh/m2
0
50
100 km
© 2011 GeoModel Solar s.r.o.

2019

- Schimbare de:
  - adresa
  - aplicatie
- Alte modalitati de prezentare a rezultatelor
  - acces la date individuale 2007 – 2016
  - unitati de masura diferite (kWh/m^2/**luna**)
  - lipsesc unele date (unghi optim lunar, H90)

http://re.jrc.ec.europa.eu/pvg_tools/en/tools.html

2019


re.jrc.ec.europa.eu/pvg_tools/en/tools.html#MR
Home
Tools
Download
Documentation
About us
News
Cursor:
Selected: 47.160, 27.585
Elevation (m): 57
Use terrain shadows:
Calculated horizon
Upload horizon file
csv
Choose File No file chosen
GRID CONNECTED
TRACKING PV
OFF-GRID
MONTHLY DATA
DAILY DATA
HOURLY DATA
TMY
MONTHLY IRRADIATION DATA
Solar radiation database*
PVGIS-CMSAF
Start year:* 2007
End year:* 2007
Irradiation:
Global horizontal irradiation
Direct normal irradiation
Global irradiation optimum angle
Global irradiation at angle:
(0-90)
Ratio:
Diffuse/global ratio
Temperature:
Average temperature
Visualize results
Download csv
MOLDOVA
ROMANIA
TRANSYLVANIAN ALPS
Cluj-Napoca
Chişinău
Iaşi
Brasov
Address:
Eg.Ispra, Italy
Go!
Lat/Lon:
Eg. 45.815
Eg. 8.611
Go!
MONTHLY IRRADIATION DATA: RESULTS
Radiation
Diffuse/Global
Temperature
Info
PDF
Summary
Provided inputs:
Location [Lat/Lon]: 47.160, 27.585
Horizon: Calculated
Database used: PVGIS-CMSAF
Start year: 2007
End year: 2007
Monthly solar irradiation estimates
Monthly irradiation [kWh/m2]
200
150
100
50
0
January '2007
March '2007
May '2007
July '2007
September '2007
November '2007
Outline of horizon
N
NE
E
W
NW
45
90

Iasi, date 2016

Month	H_h	H_{opt}	DNI	D/G	T_{24h}
Jan	34.8	55.5	39	0.67	-2.3
Feb	50.5	72.2	50	0.63	4.1
Mar	100	128	94	0.51	5.2
Apr	147	167	141	0.43	12.4
May	168	169	141	0.46	14.2
Jun	184	180	162	0.4	20.2
Jul	215	215	216	0.33	21.7
Aug	174	191	185	0.35	20.4
Sep	130	164	149	0.38	17
Oct	55.2	73.7	54	0.59	6.6
Nov	36.3	58.5	44	0.62	2.8
Dec	29.6	49.2	35	0.68	-1

Iasi, date 2015

Month	H_h	H_{opt}	DNI	D/G	T_{24h}
Jan	29.5	45.6	31	0.71	-0.9
Feb	50.6	73.5	53	0.61	-0.2
Mar	95.4	123	94	0.51	4.1
Apr	142	160	134	0.44	9.1
May	190	193	177	0.39	16.6
Jun	209	205	200	0.35	19.7
Jul	199	200	187	0.36	22.8
Aug	173	189	180	0.35	22.6
Sep	113	140	118	0.42	17.6
Oct	73.7	107	85	0.51	8
Nov	38.3	61.6	48	0.59	6.1
Dec	34.7	64	52	0.6	1.1

Iasi, date 2016

Month	H_h	H_{opt}	DNI	D/G	T_{24h}
Jan	34.8	55.5	39	0.67	-2.3
Feb	50.5	72.2	50	0.63	4.1
Mar	100	128	94	0.51	5.2
Apr	147	167	141	0.43	12.4
May	168	169	141	0.46	14.2
Jun	184	180	162	0.4	20.2
Jul	215	215	216	0.33	21.7
Aug	174	191	185	0.35	20.4
Sep	130	164	149	0.38	17
Oct	55.2	73.7	54	0.59	6.6
Nov	36.3	58.5	44	0.62	2.8
Dec	29.6	49.2	35	0.68	-1

Hh: Irradiation on horizontal plane (kWh/m2/month)

Hopt: Irradiation on optimally inclined plane (kWh/m2/month)

DNI: Direct normal irradiation (kWh/m2/month)

D/G: Ratio of diffuse to global irradiation (-)

T24h: 24 hour average of temperature (−C)

Iasi, date 2020

Month	H(h)_m	H(i_opt)_m	Hb(n)_m	Kd	T2m
Jan	42.42	84.29	77.65	0.48	0.2
Feb	61.58	97.82	82.35	0.48	3.4
Mar	112.28	150.87	130.45	0.41	6.6
Apr	175.65	205.88	199.18	0.33	11.3
May	145.46	144.31	112.26	0.5	14.2
Jun	181.37	173.26	148.87	0.44	21.4
Jul	196.06	192.45	171.95	0.4	22.7
Aug	186.03	202.9	189.24	0.36	23.6
Sep	137.27	177.73	161.36	0.35	19.2
Oct	69.29	97.6	70.7	0.55	13.6
Nov	36.67	59.98	44.53	0.6	4.6
Dec	20.75	31.54	20.21	0.74	2.4

Iasi, date 2020

Month	H(h)_m	H(i_opt)_m	Hb(n)_m	Kd	T2m
Jan	42.42	84.29	77.65	0.48	0.2
Feb	61.58	97.82	82.35	0.48	3.4
Mar	112.28	150.87	130.45	0.41	6.6
Apr	175.65	205.88	199.18	0.33	11.3
May	145.46	144.31	112.26	0.5	14.2
Jun	181.37	173.26	148.87	0.44	21.4
Jul	196.06	192.45	171.95	0.4	22.7
Aug	186.03	202.9	189.24	0.36	23.6
Sep	137.27	177.73	161.36	0.35	19.2
Oct	69.29	97.6	70.7	0.55	13.6
Nov	36.67	59.98	44.53	0.6	4.6
Dec	20.75	31.54	20.21	0.74	2.4

H(h)_m: Irradiation on horizontal plane (kWh/m2/mo)

H(i_opt)_m: Irradiation on optimally inclined plane (kWh/m2/mo)

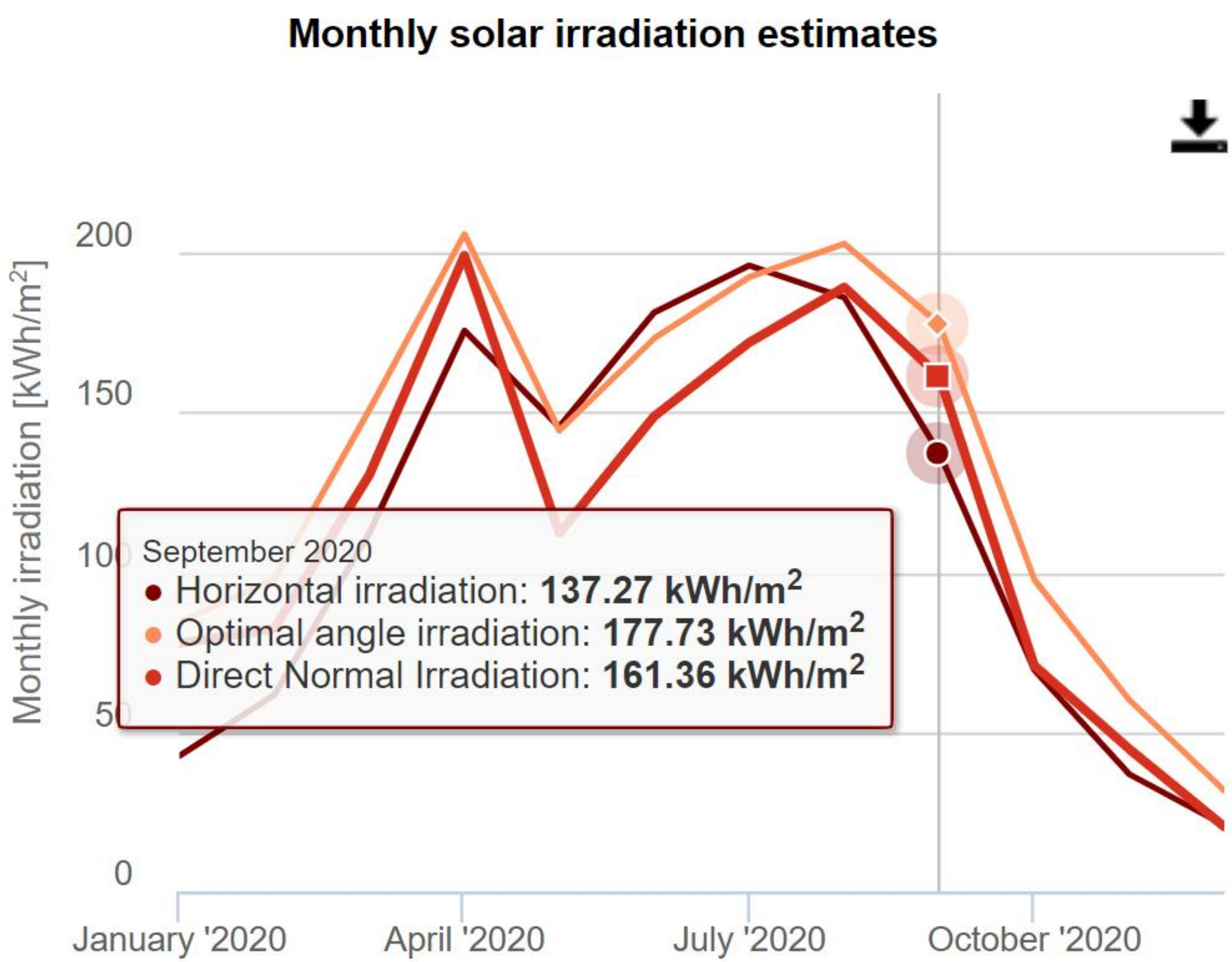
Hb(n)_m: Monthly beam (direct) irradiation on a plane always normal to sun rays (kWh/m2/mo)

Kd: Ratio of diffuse to global irradiation (-)

T2m: 24 hour average of temperature (degree Celsius)

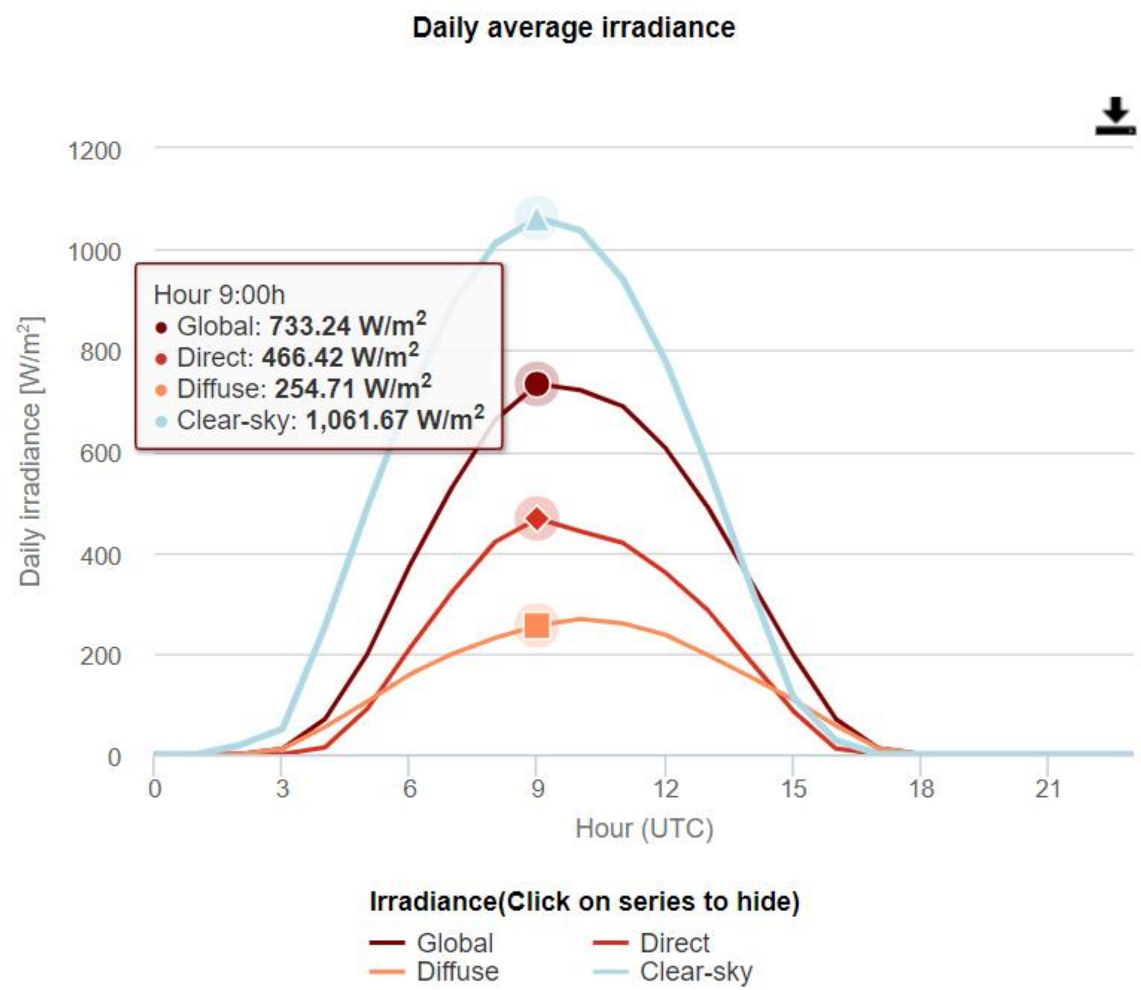
Iasi, date 2020

- Lunar
  - $kWh/m^2/luna$
  - Unghi optim (an) in csv



Iasi, date 2020

- Zi (mai)
  - W/m²
  - Ore in UTC!! (−3h)
  - Clear sky – conditii ideale



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- http://ocw.mit.edu/
- **MIT Course Number** 2.627
- Fundamentals of Photovoltaics

- http://re.jrc.ec.europa.eu/pvg_tools/en/tools.html
- http://www.pveducation.org/