Optoelectronică, structuri şi tehnologii

Curs 13

2015/2016

Examen/Colocviu

- Examen
  - Sambata, 16.01.2016, P2, ora 11
- Site http://rf-opto.etti.tuiasi.ro
  - barem minim 7 prezente
  - lista bonus-uri acumulate

Utilizare celule solare

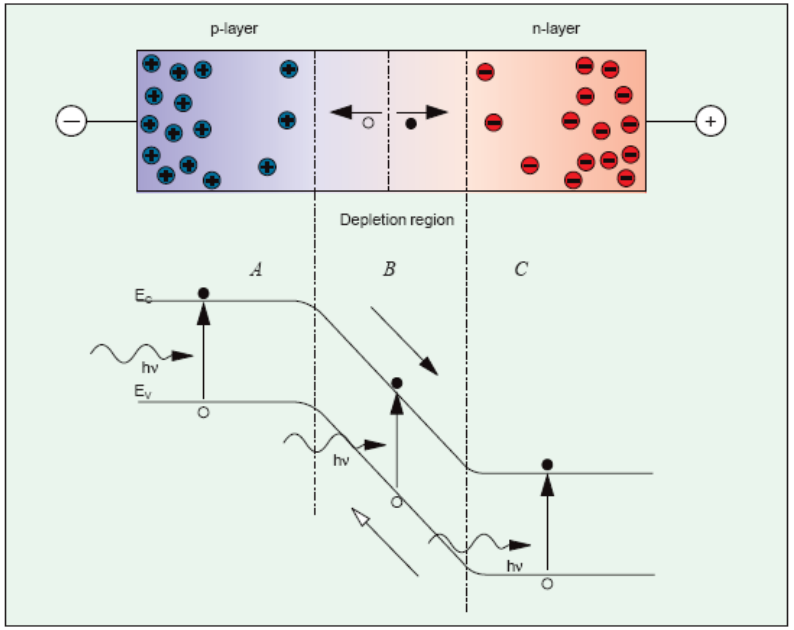
Capitolul 12

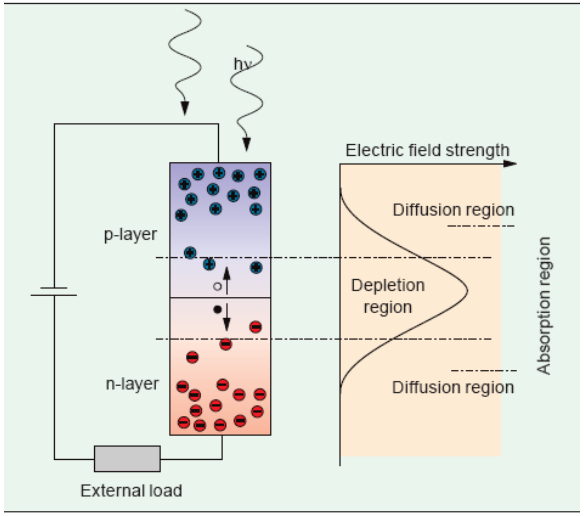
Fotodioda

Recapitulare

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

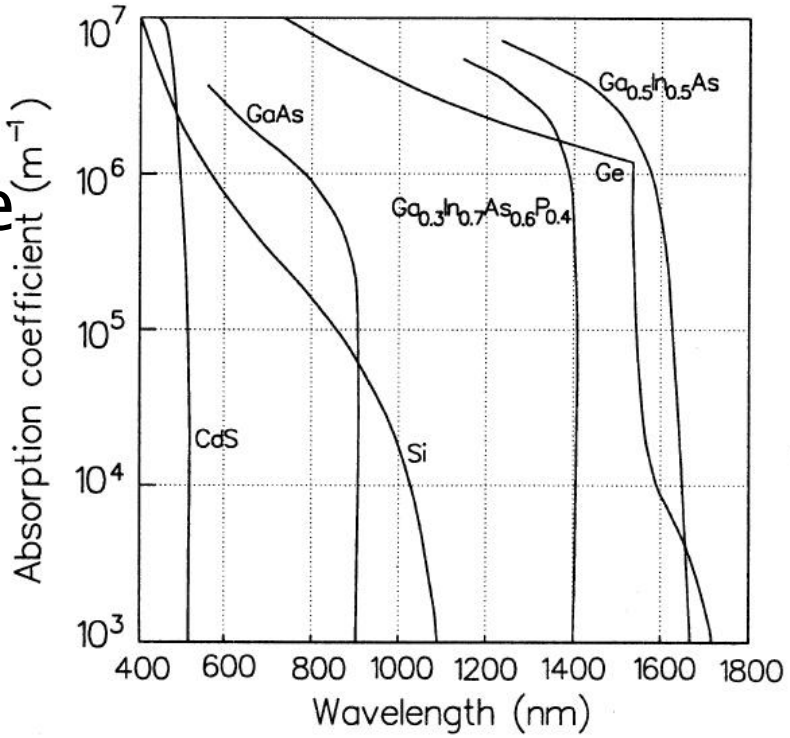
$$\lambda_{\max} = \frac{hc}{E_g}$$

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

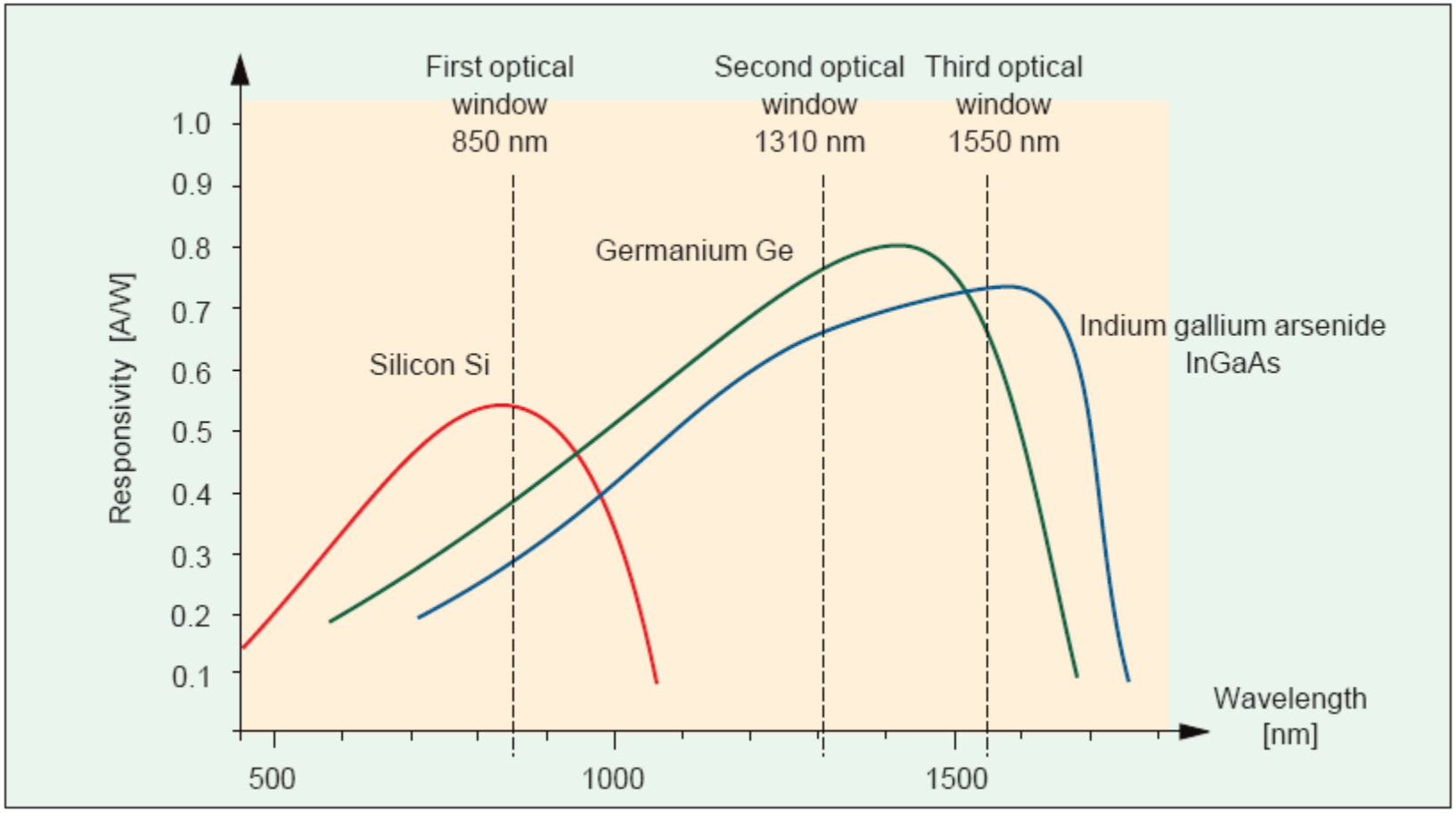
$$P(w) = P_i \cdot e^{-\alpha \cdot d} \cdot \left(1 - e^{-\alpha \cdot w}\right) \cdot \left(1 - R_f\right)$$

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

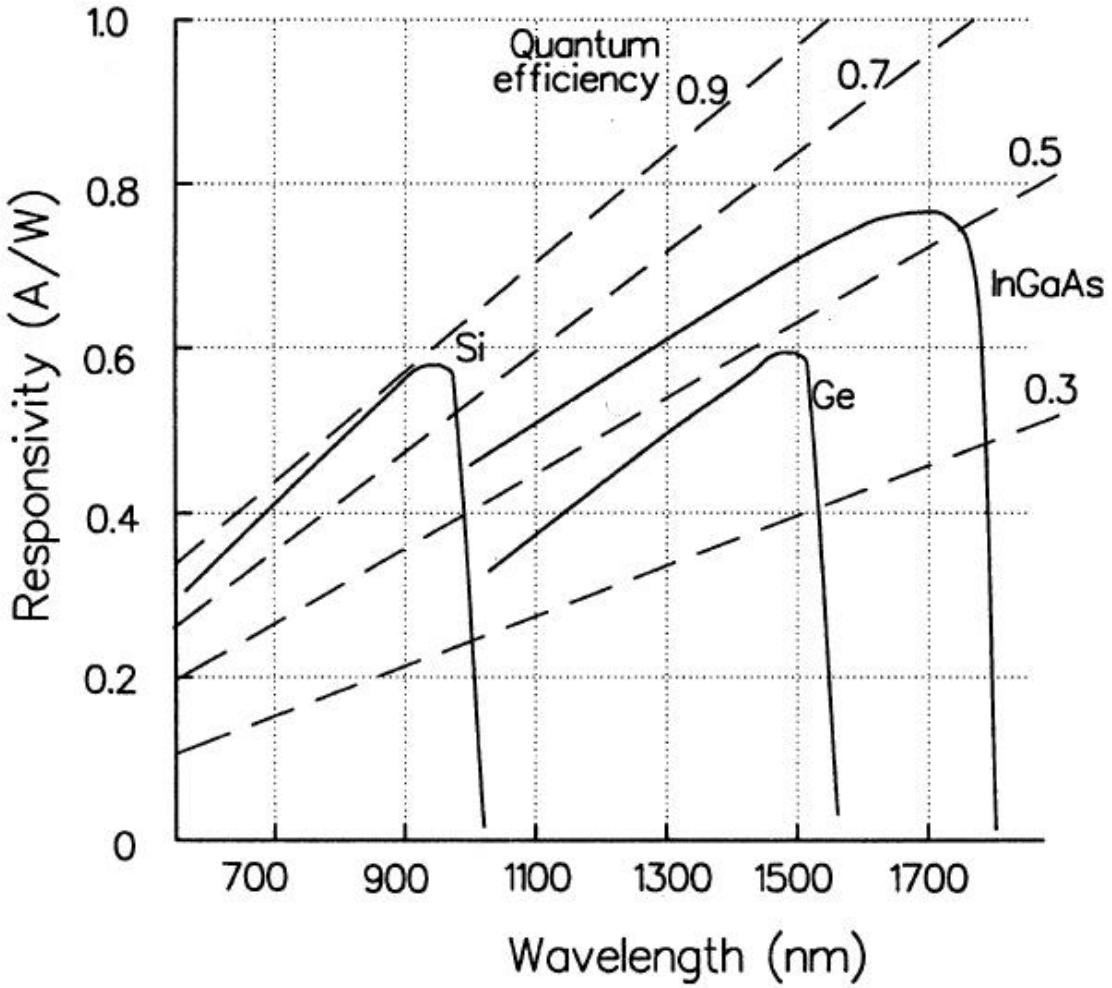
$$\eta = \frac{I/e}{P/h\nu}$$

- Responzivitatea

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

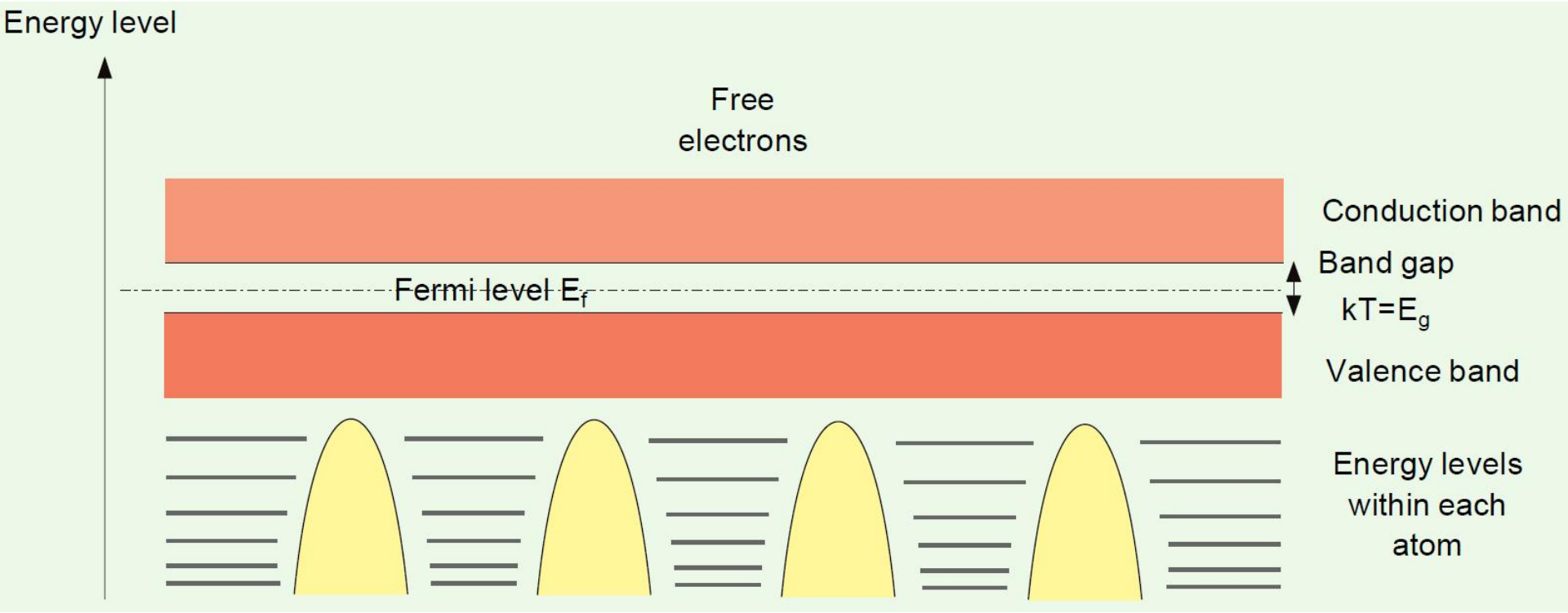
Fotodiode – marimi caracteristice

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



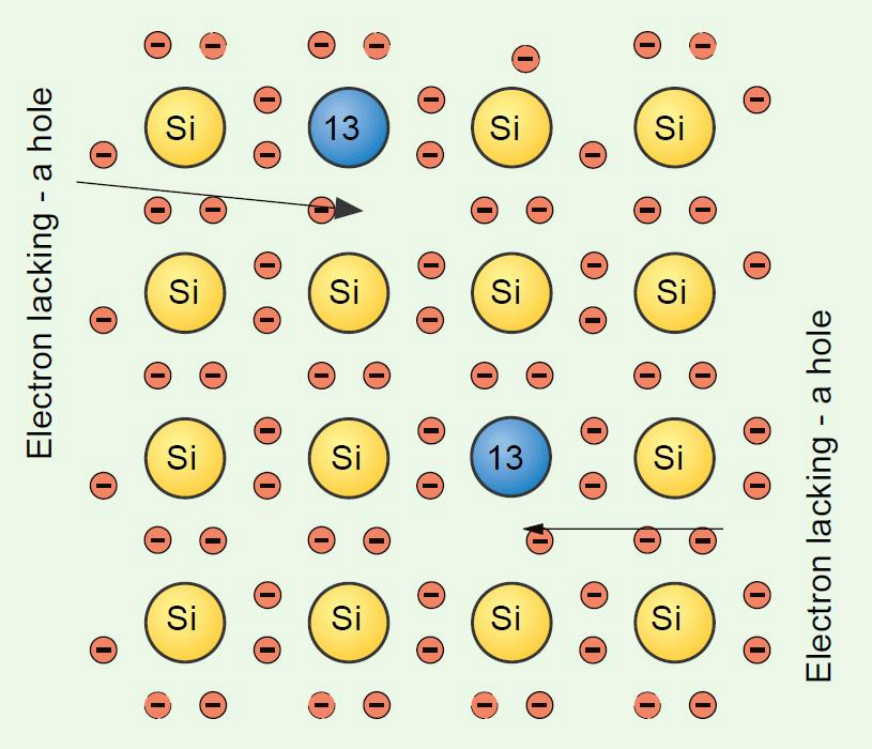
Efect fotovoltaic

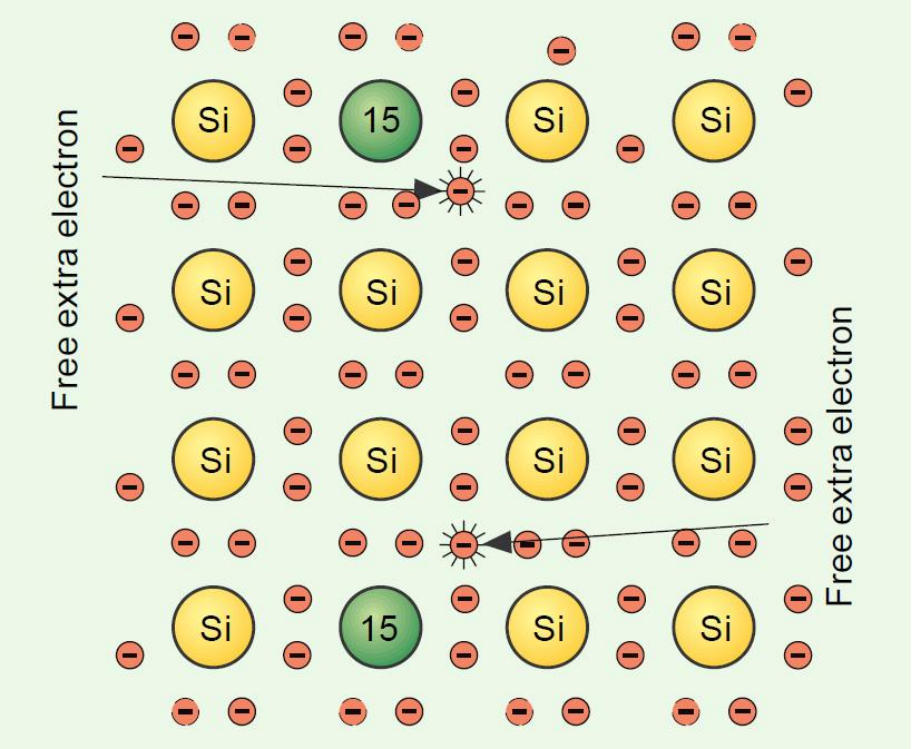
- joncțiunea pn



Efect fotovoltaic

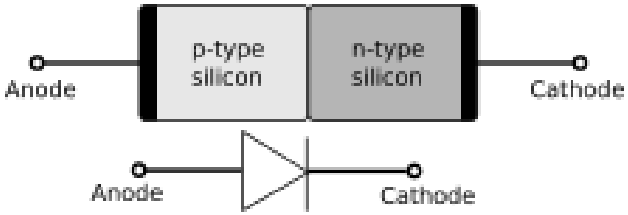
- joncțiunea pn



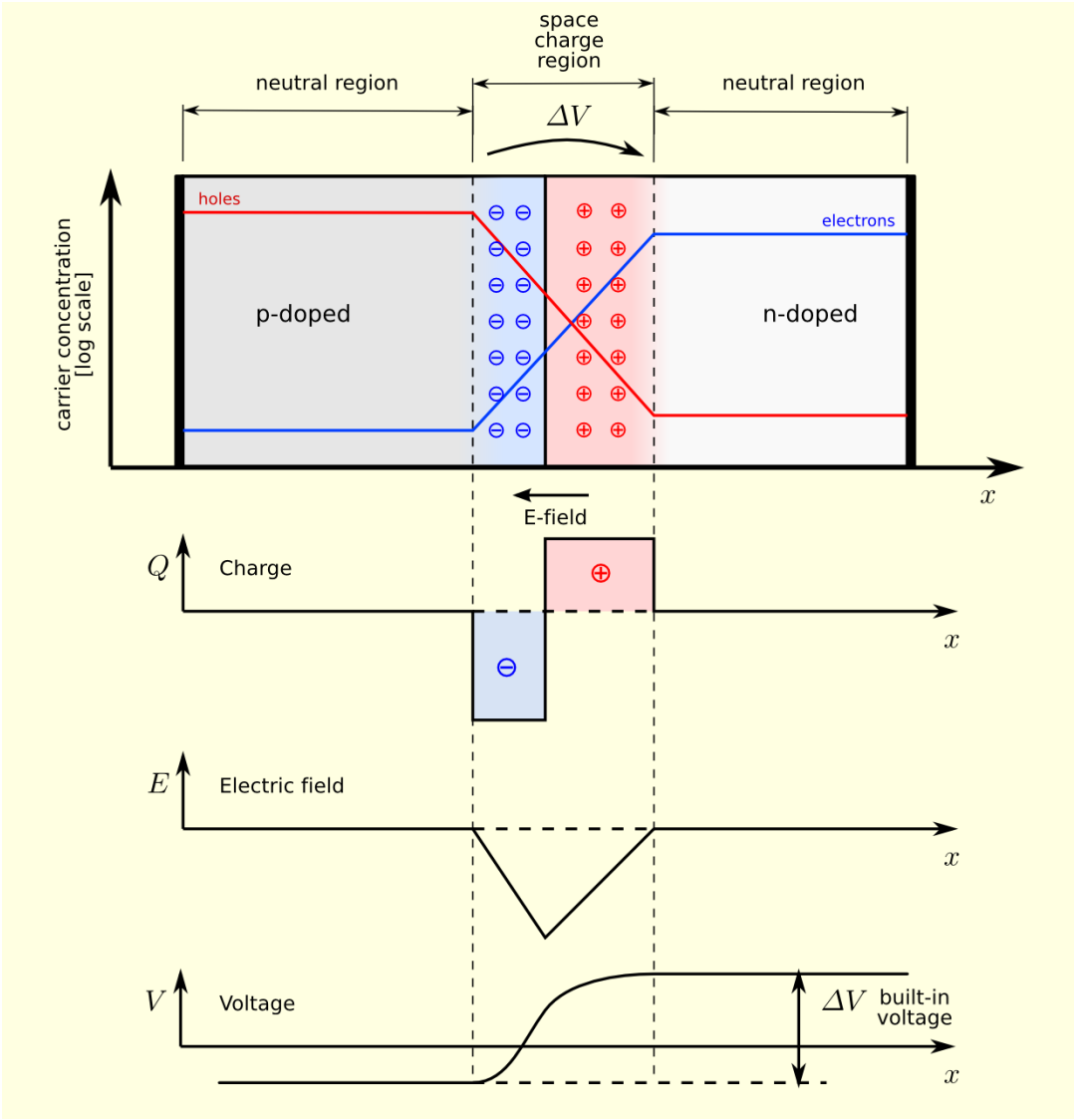


Efect fotovoltaic

- joncțiunea pn

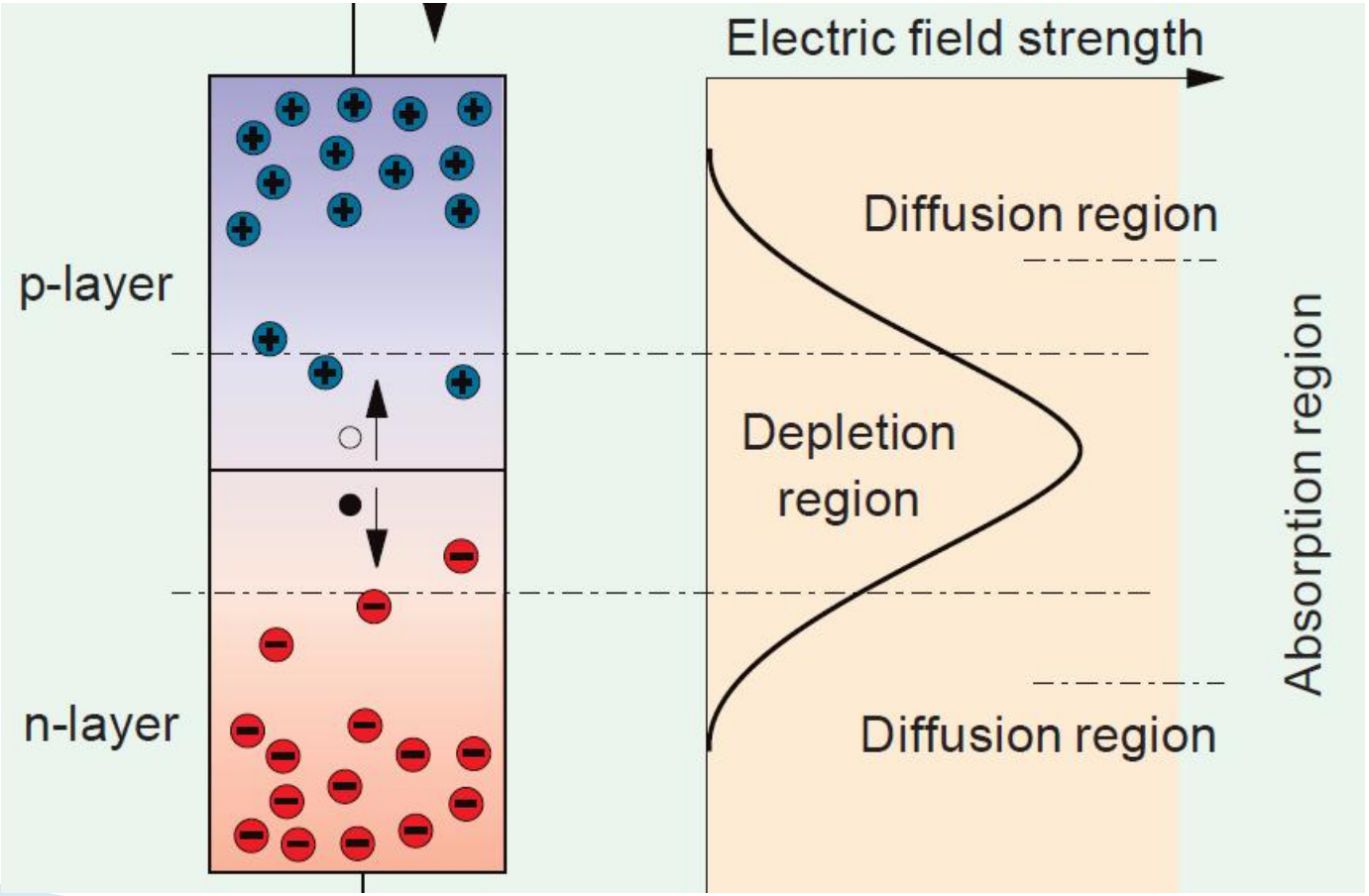


$$V > V_D$$



Efect fotovoltaic

- joncțiunea pn / Fotodioda

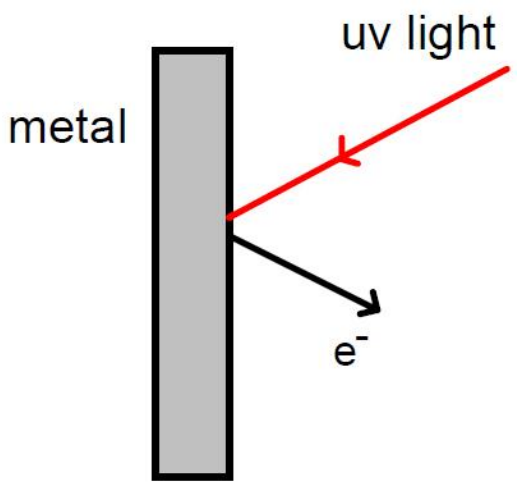


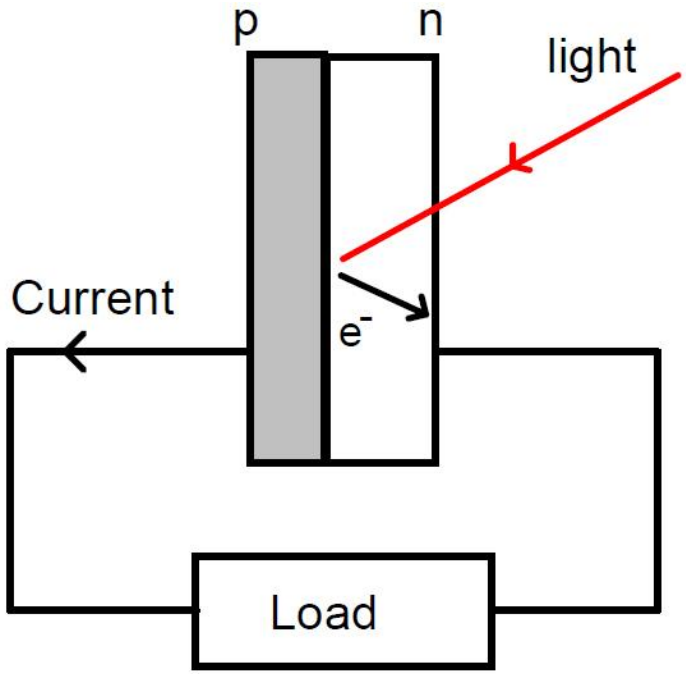
Efect fotovoltaic

- 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)



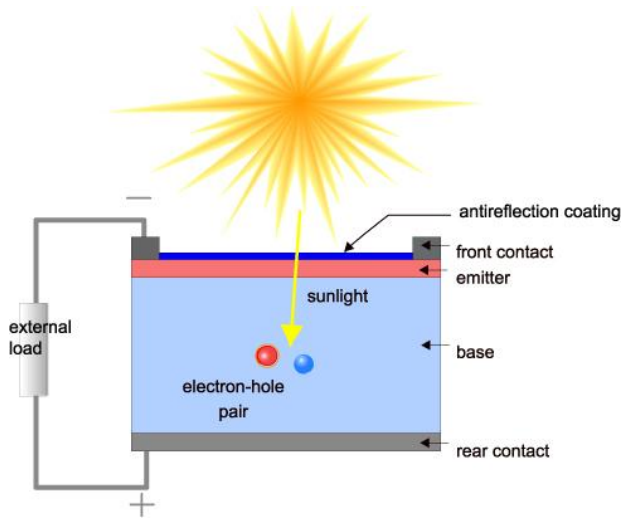


Efect fotovoltaic

- 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)

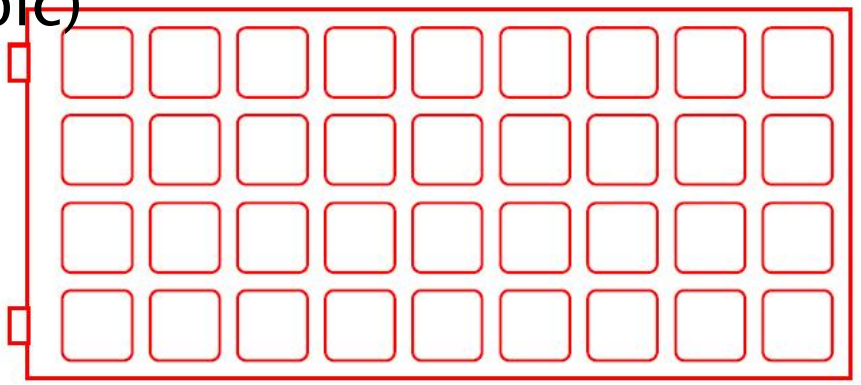
Celula solara (fotovoltaica)

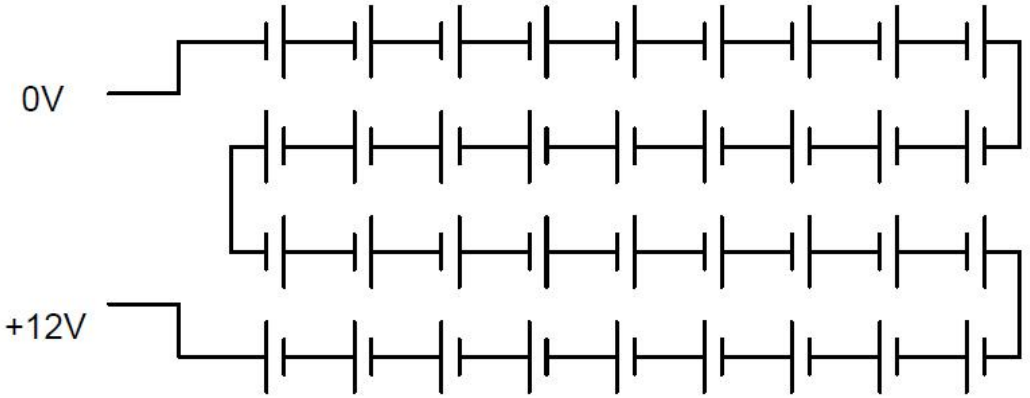
- in principiu o dioda
  - cu arie mare (~100cm^2)
  - cu suprafata tratata antireflectorizant
  - genereaza o tensiune electromotoare de 0.5÷1V
  - genereaza curenti de scurtcircuit de x0 mA/cm^2



Celula solara (fotovoltaica)

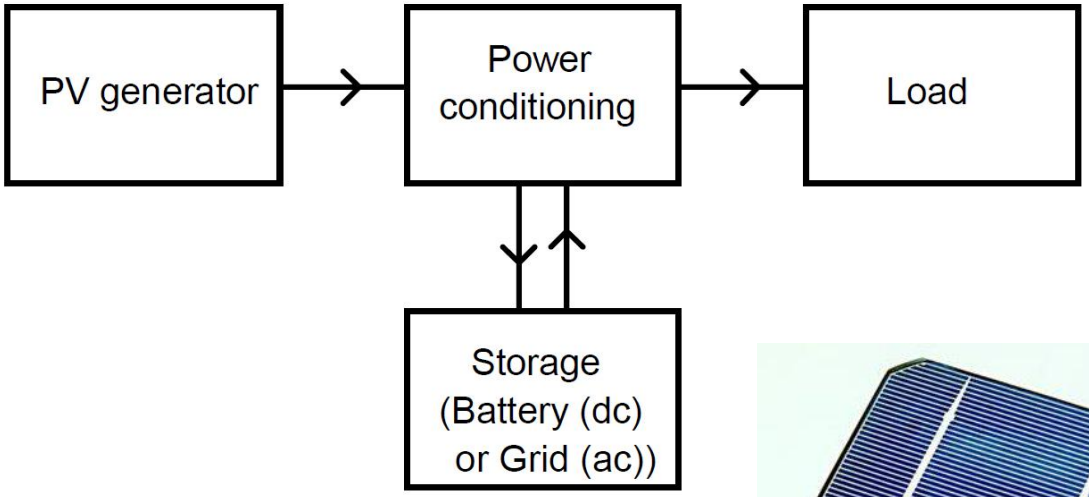
- pentru utilizare in practica
  - module de 28 – 36 de celule conectate in serie
  - creste tensiunea la 12V (tipic)

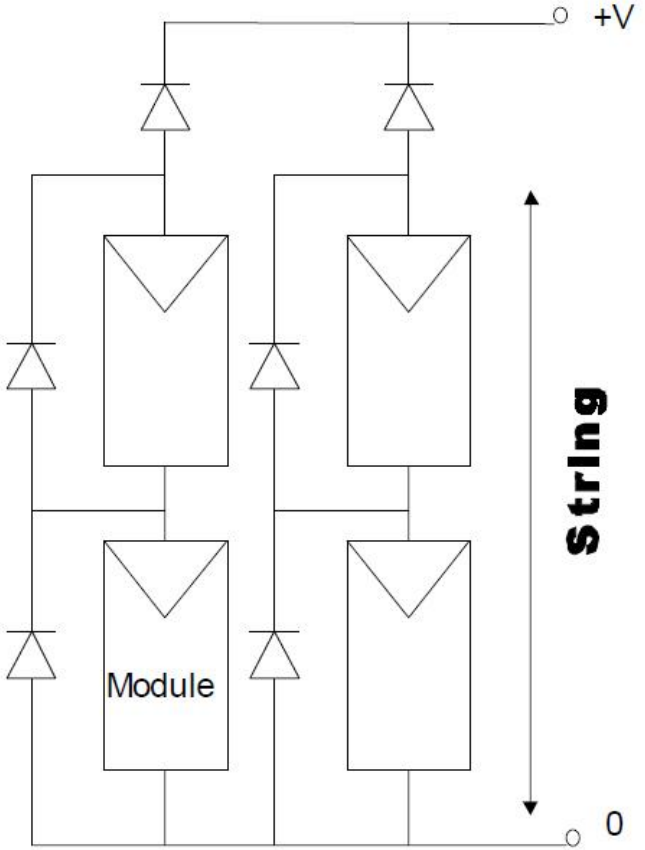




Celula solara (fotovoltaica)

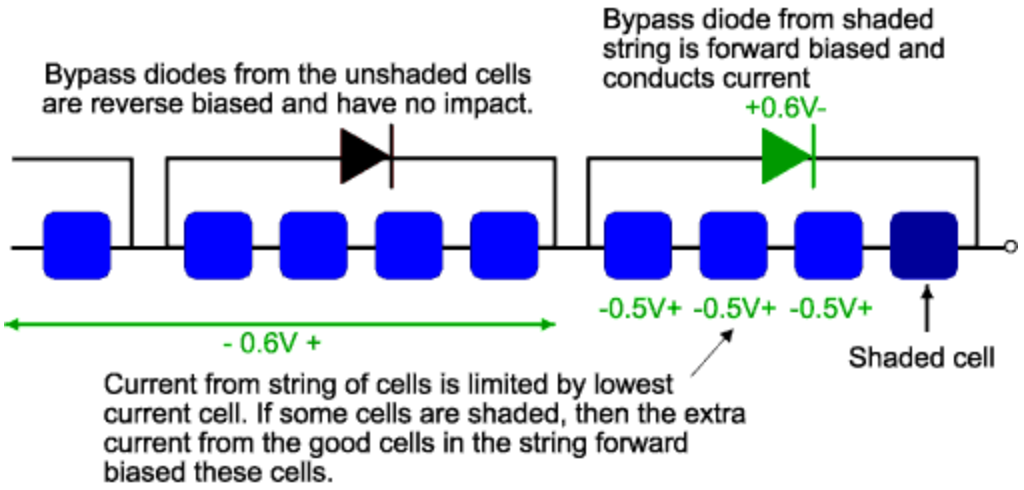
- pentru utilizare in practica
  - modulele sunt conectate in serie si/sau paralel pentru obtinerea tensiunilor/curentilor necesari pentru aplicatie

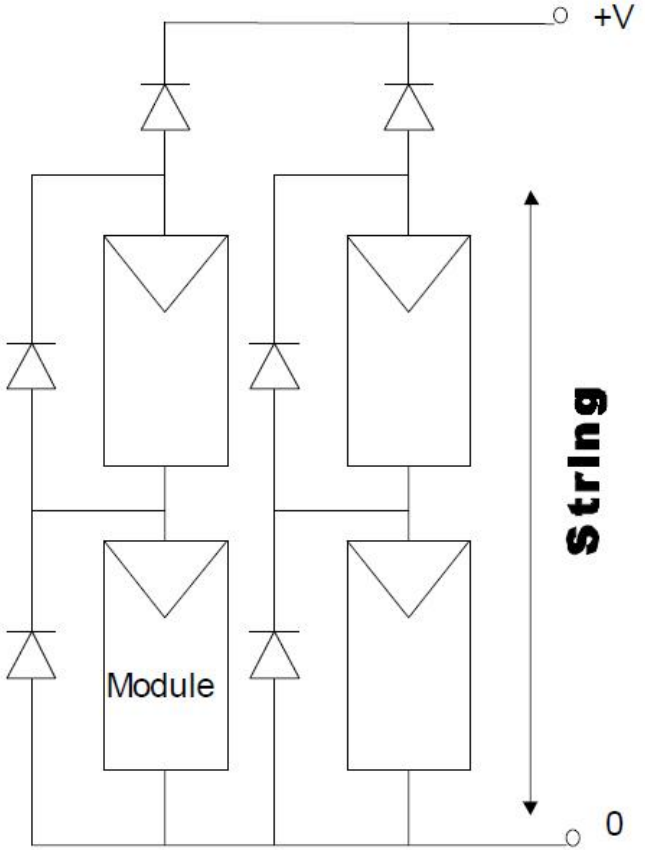




Celula solara (fotovoltaica)

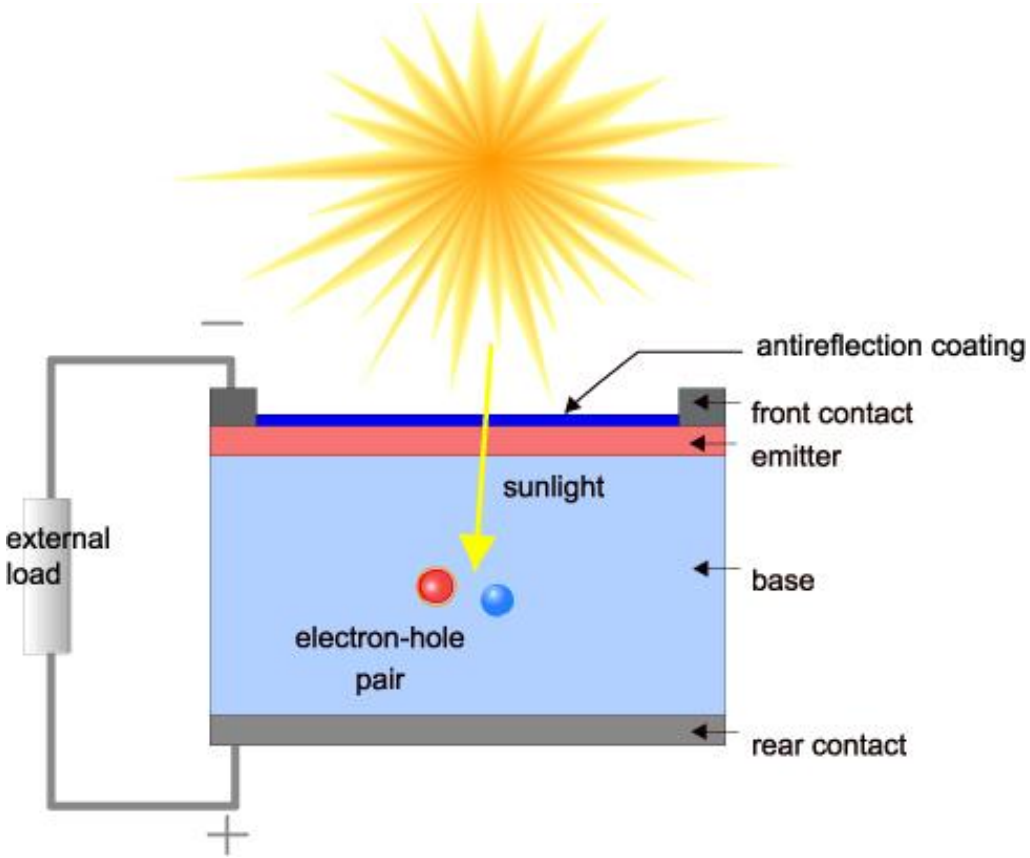
- pentru utilizare in practica
  - diode pentru flexibilitate





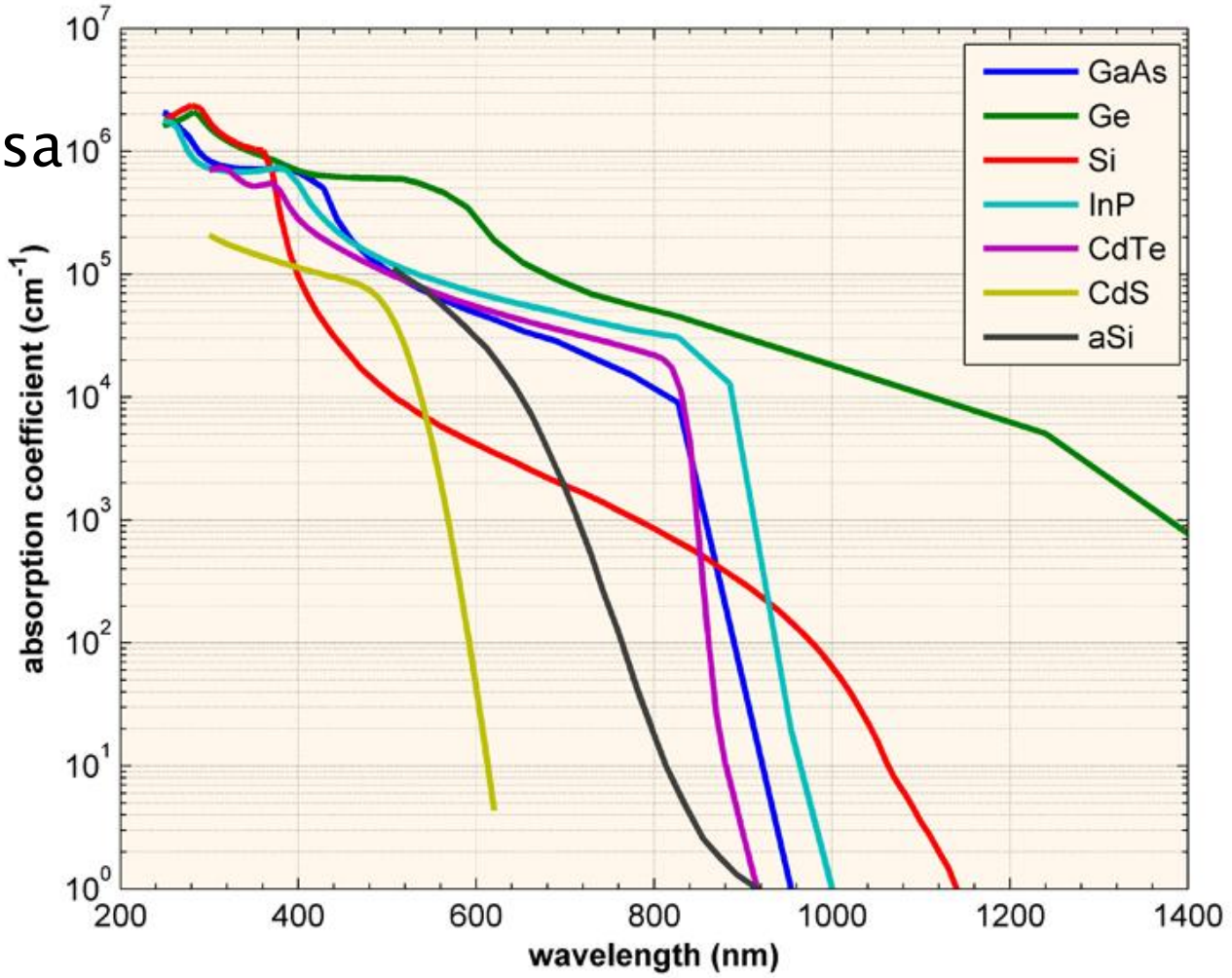
Celula solara (fotovoltaica)

- in principiu o dioda



Celula solara

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



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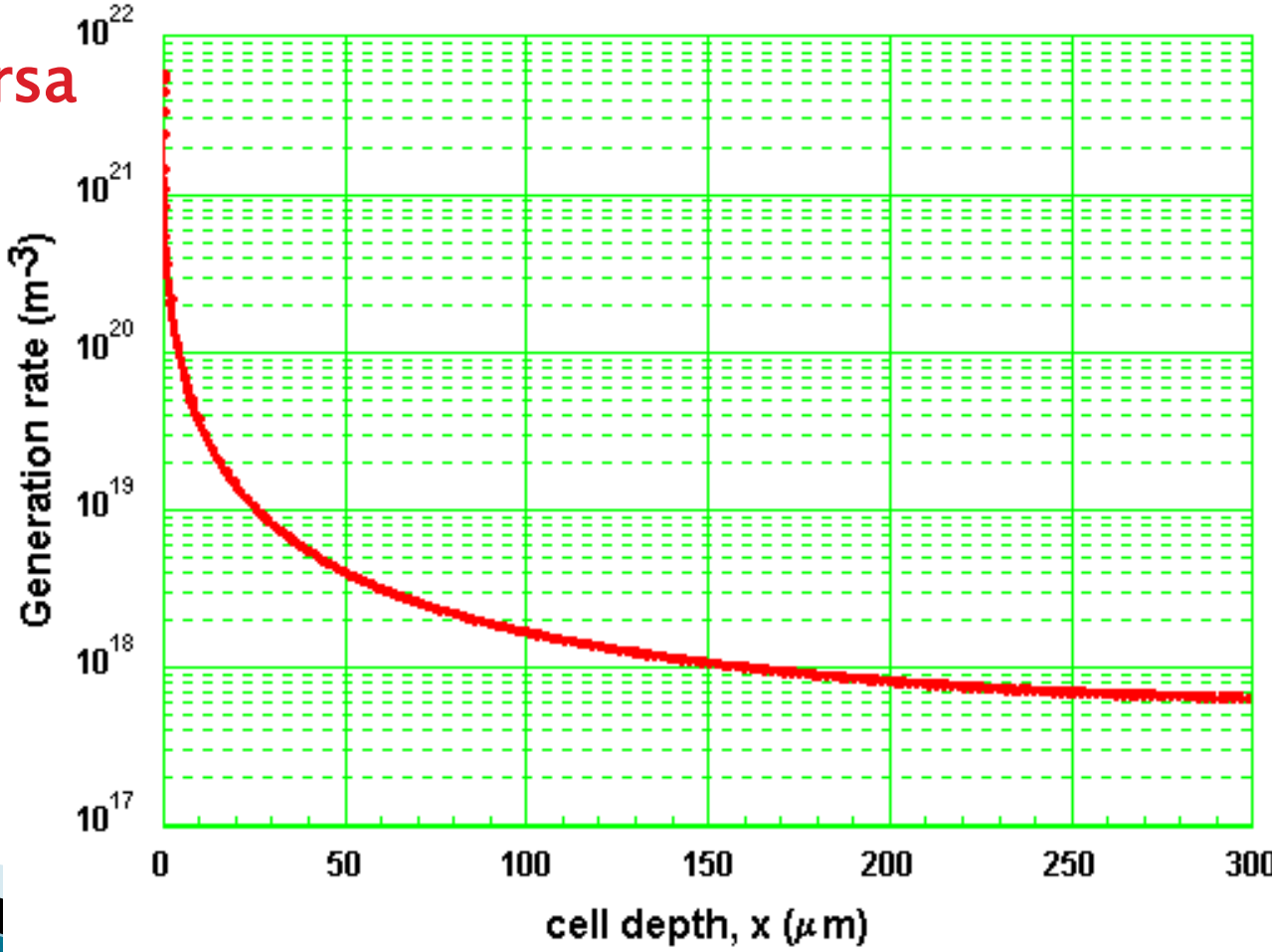
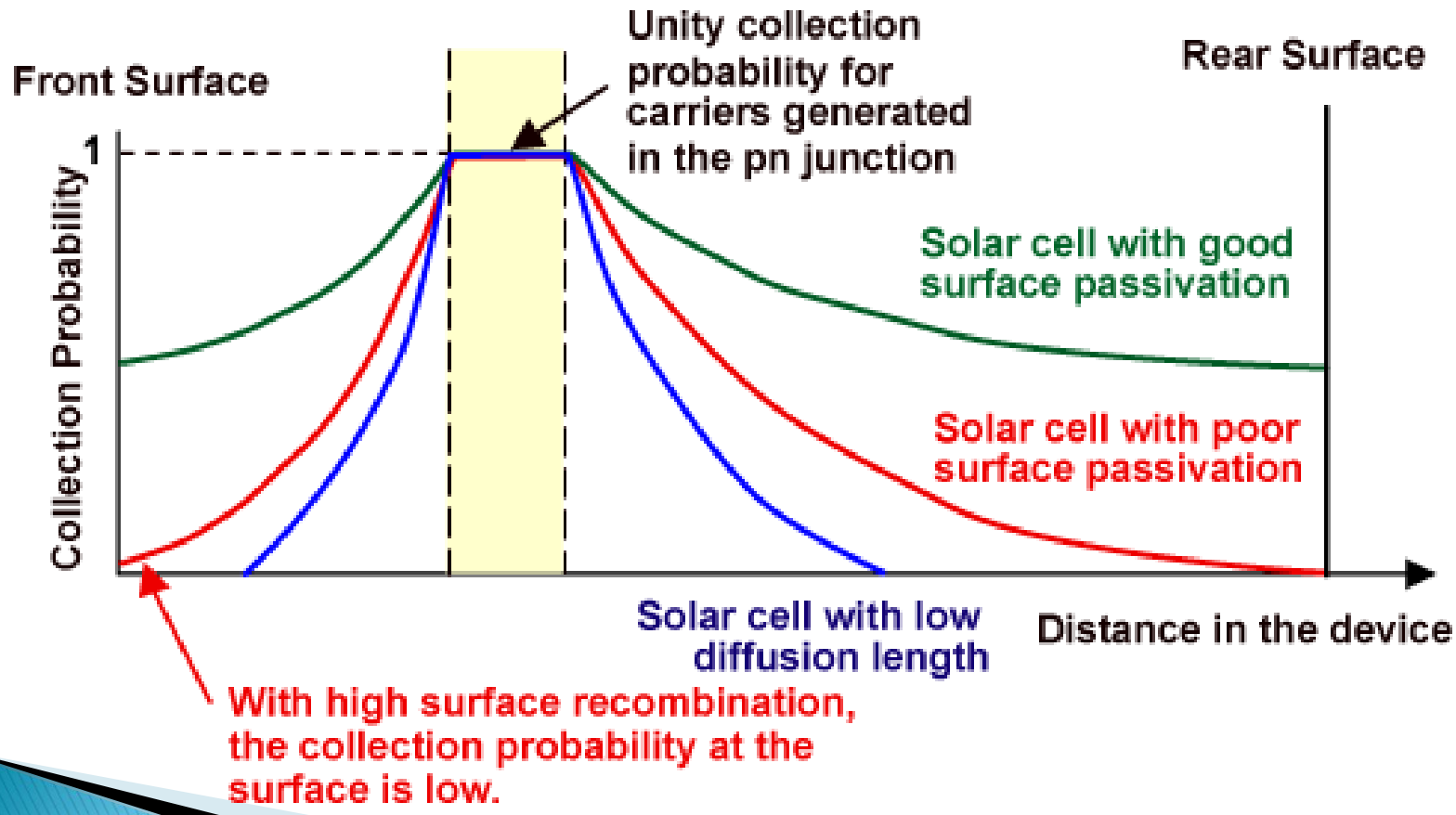


Celula solara

- probabilitate de captura a purtatorilor



Celula solara/Fotodioda

- Energia necesara pentru eliberarea unei perechi electron gol

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

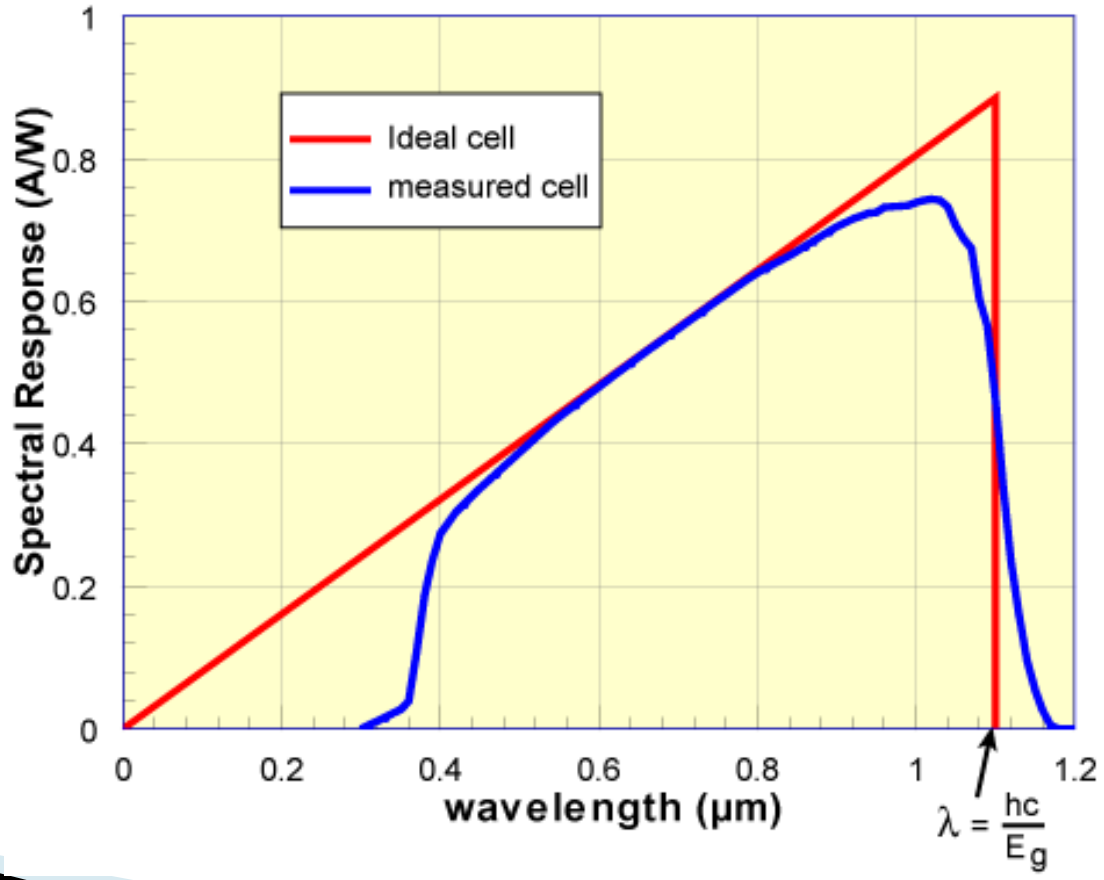
- Lungime de unda de taiere

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

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

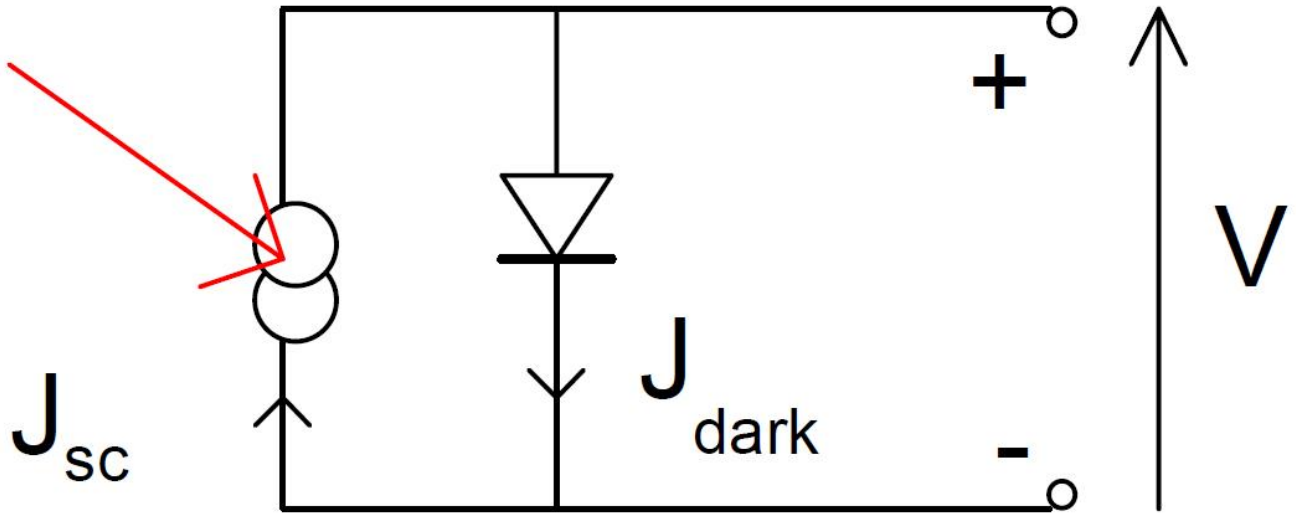
Celula solara

- raspuns spectral



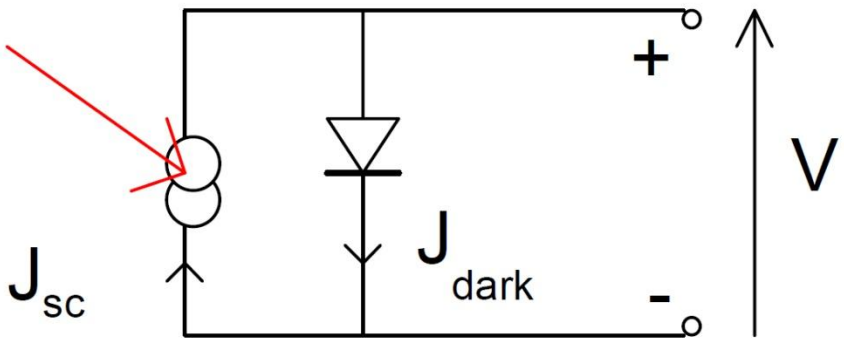
Celula solara

- 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

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

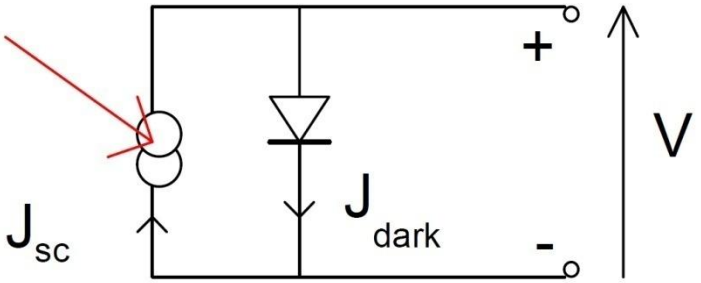
  - adaugarea curentului generat de fotoni

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

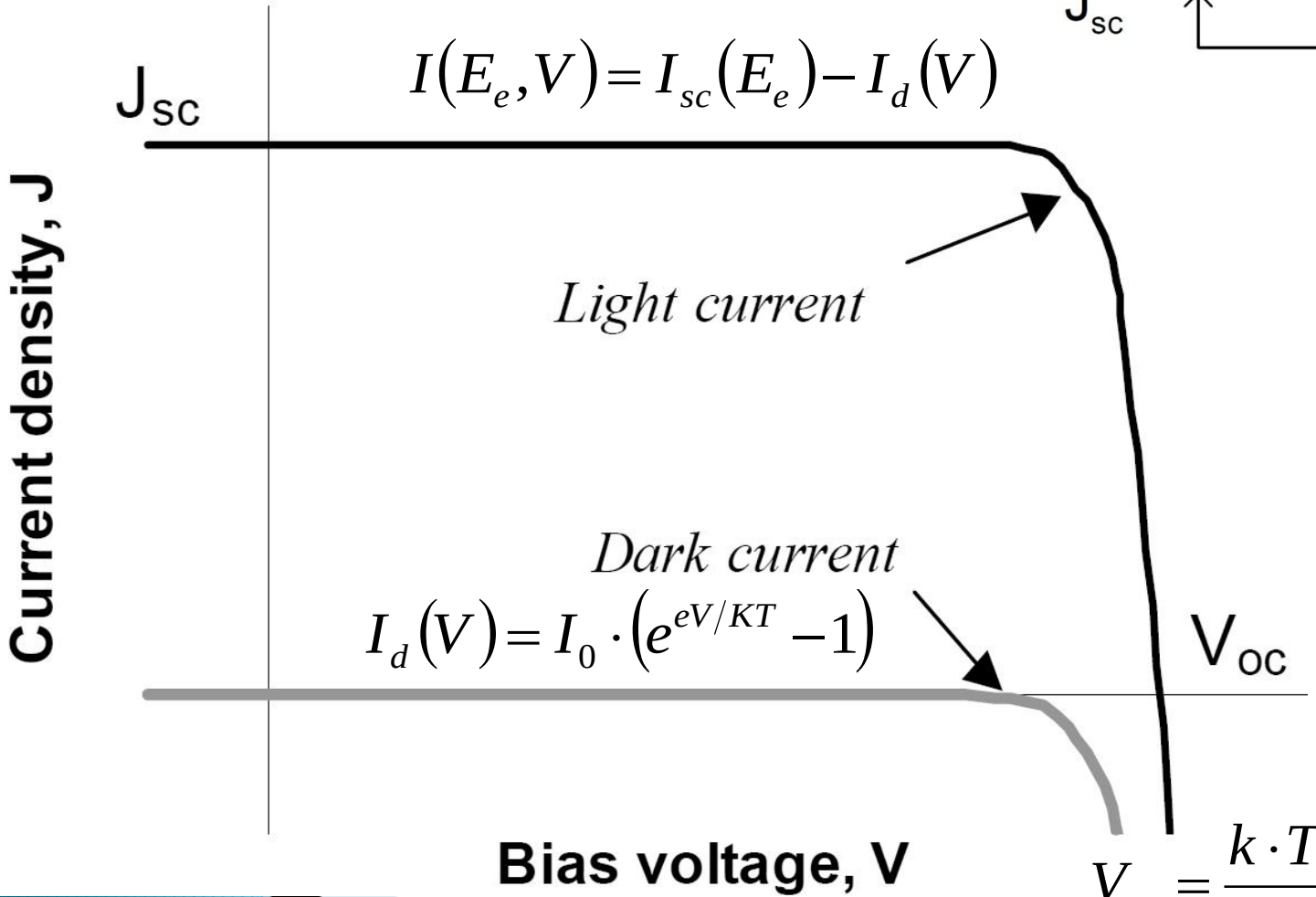
  - tensiunea in gol

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

Celula solara



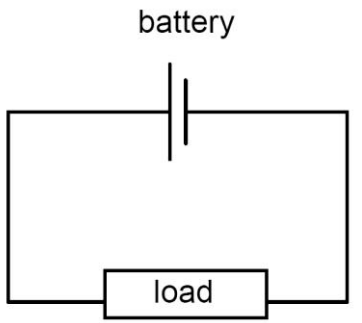
$$I(E_e, V) = I_{sc}(E_e) - I_d(V)$$

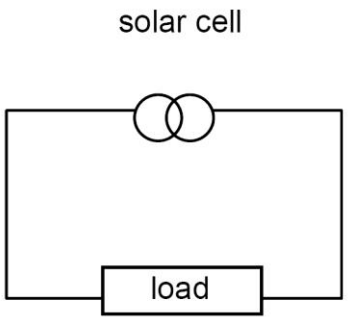


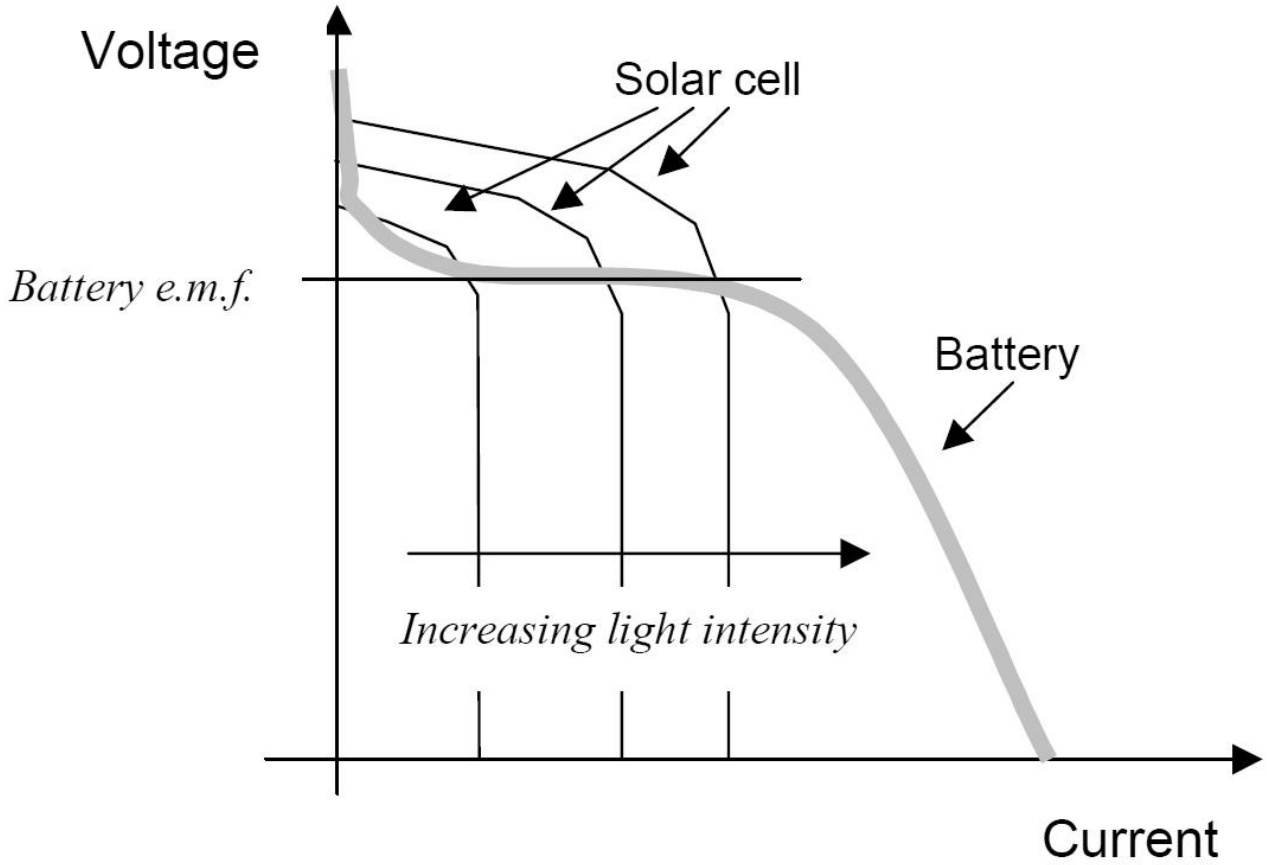
$$V_{oc} = \frac{k \cdot T}{e} \cdot \ln\left(\frac{I_{sc}(E_e)}{I_0} - 1\right)$$

Celula solara

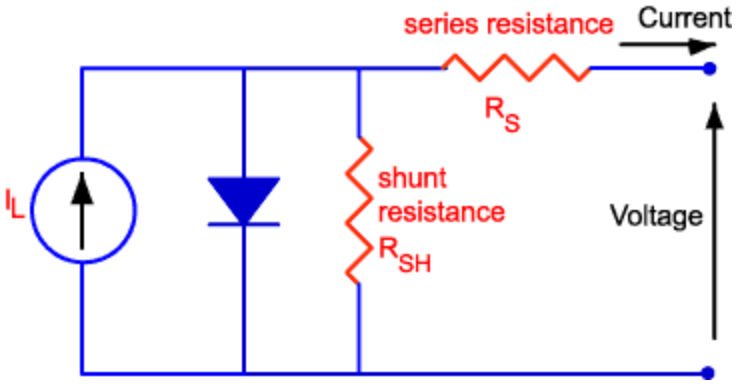
- poate fi folosita in loc de baterie intr-un circuit electric
  - cu anumite diferente

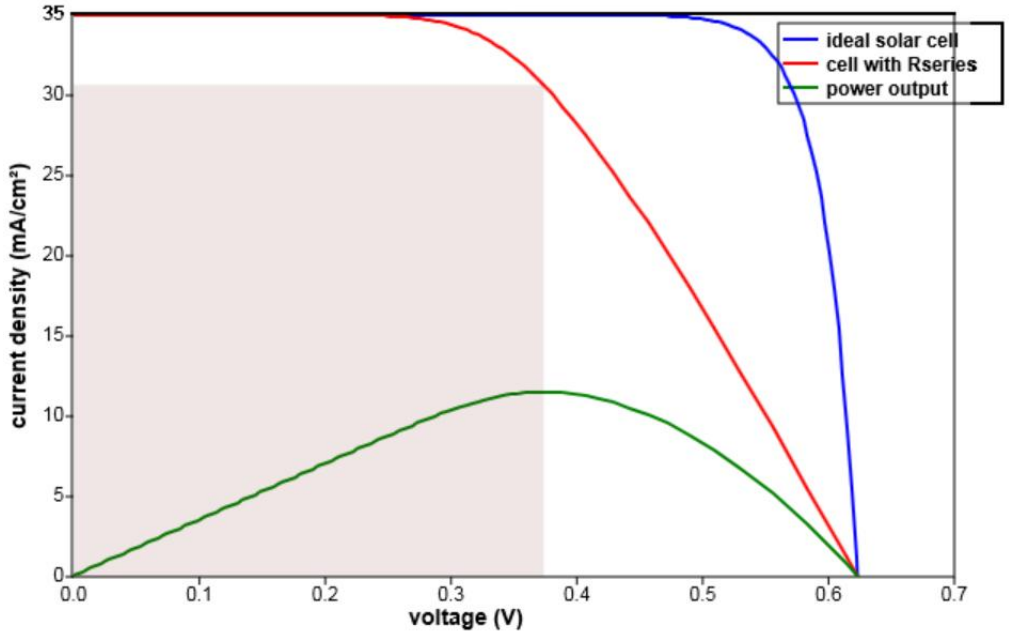


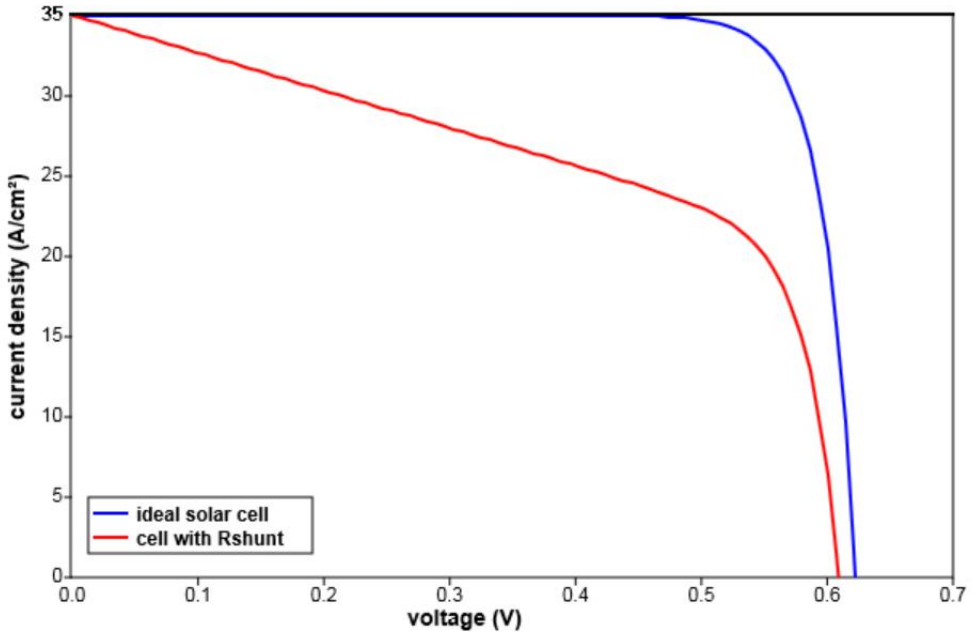




Efect pierderi





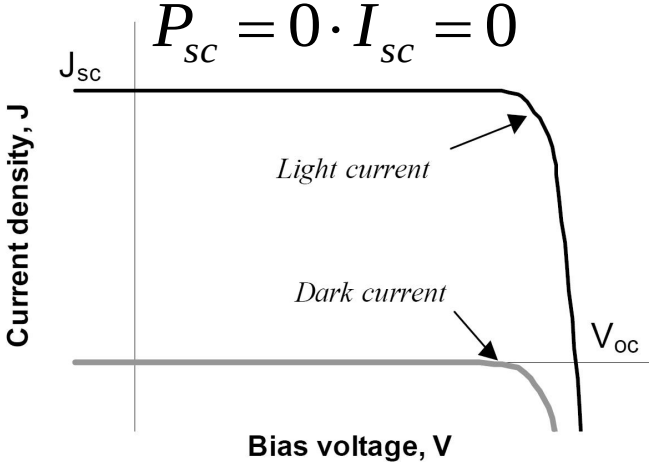


Celula solara

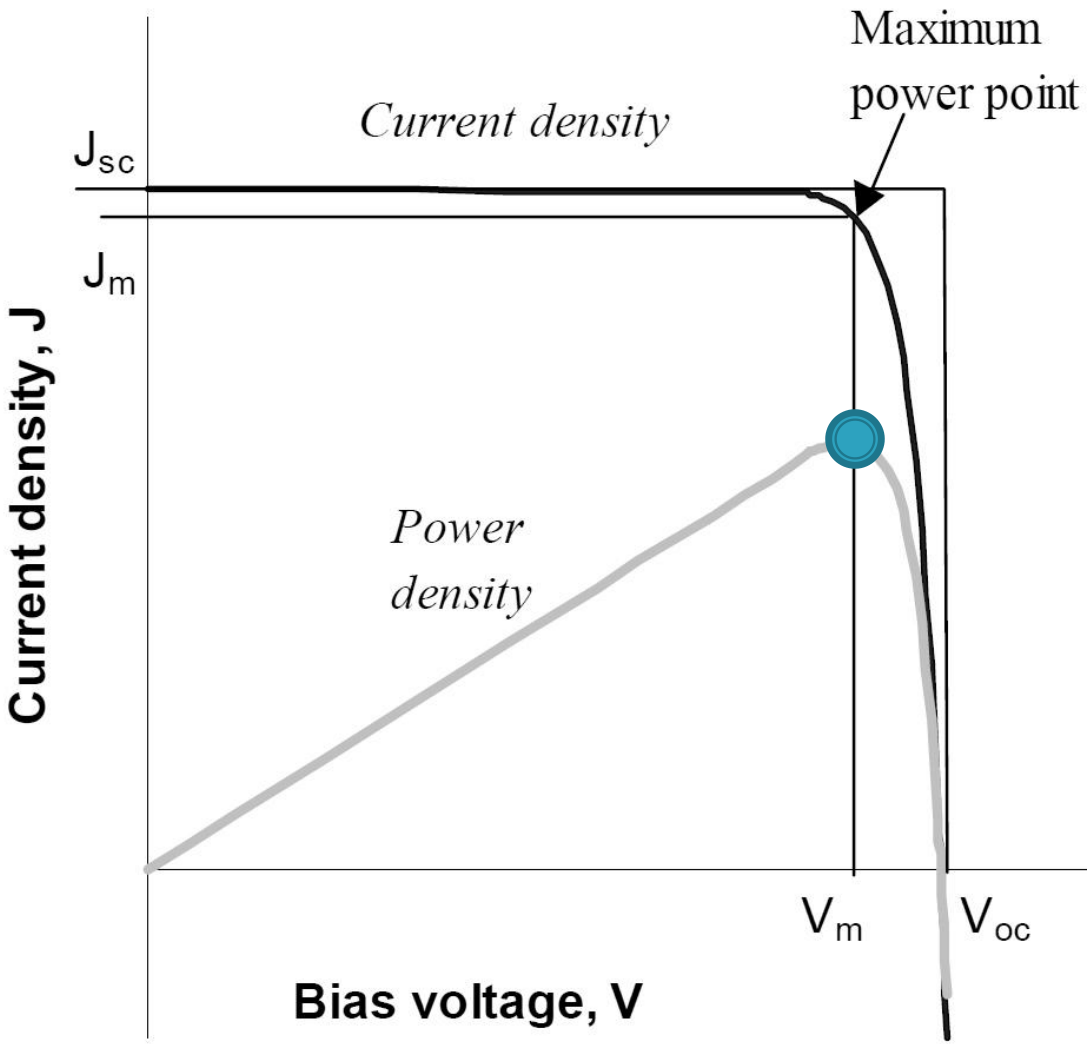
- Putere generata

$$P = V \cdot I$$

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

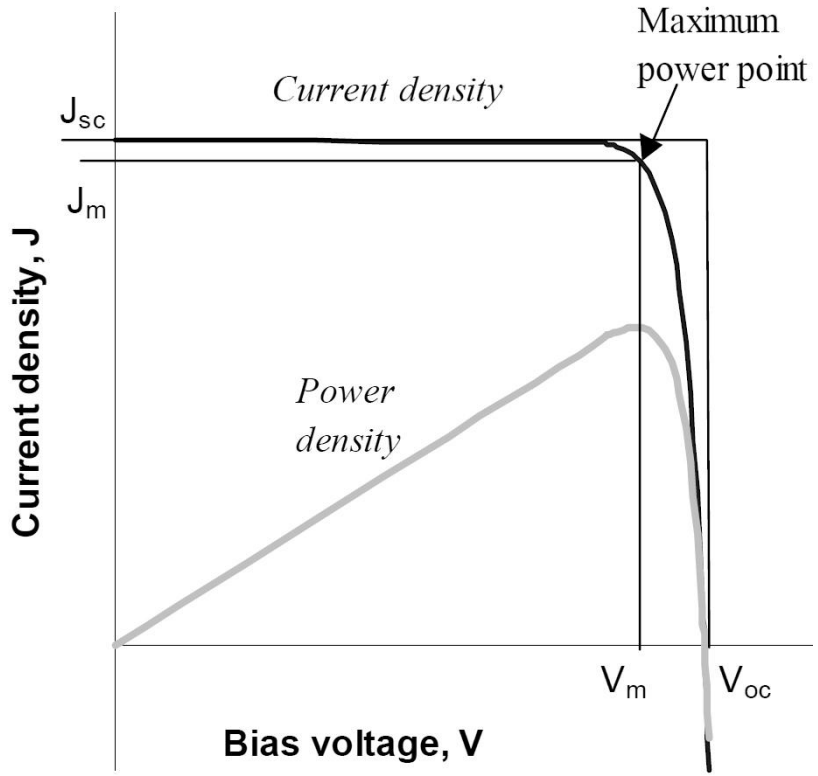


$$P_{oc} = V_{oc} \cdot 0 = 0$$



Celula solara

- Putere generata



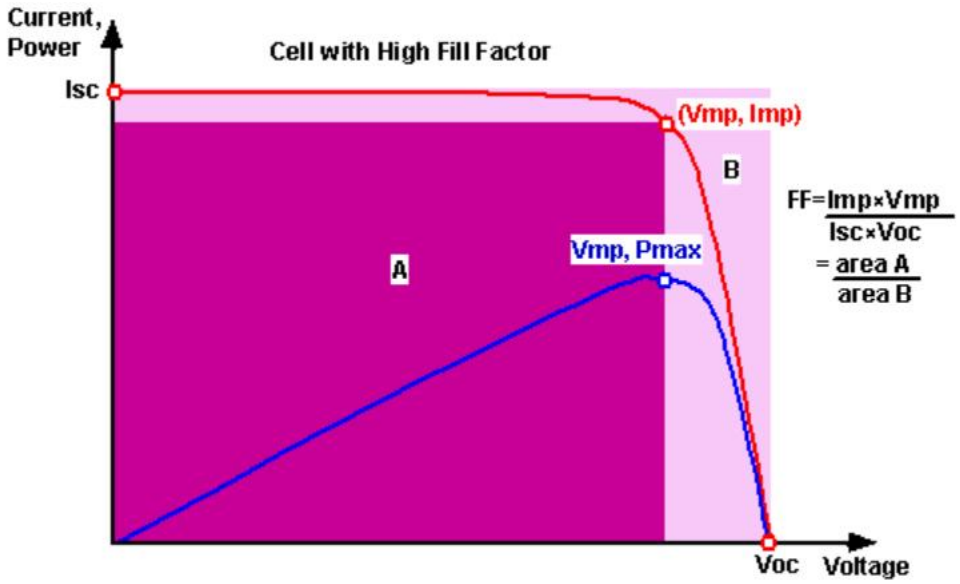
$$P_m = V_{pm} \cdot I_{pm}$$

- 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

Celula solara

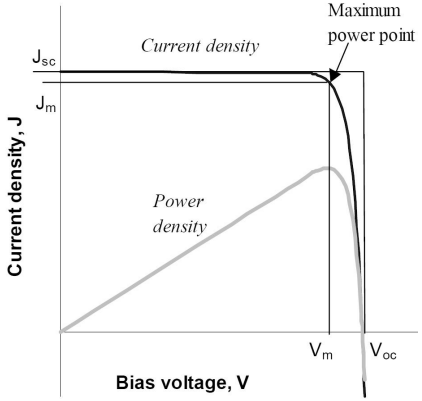
- Factor de umplere

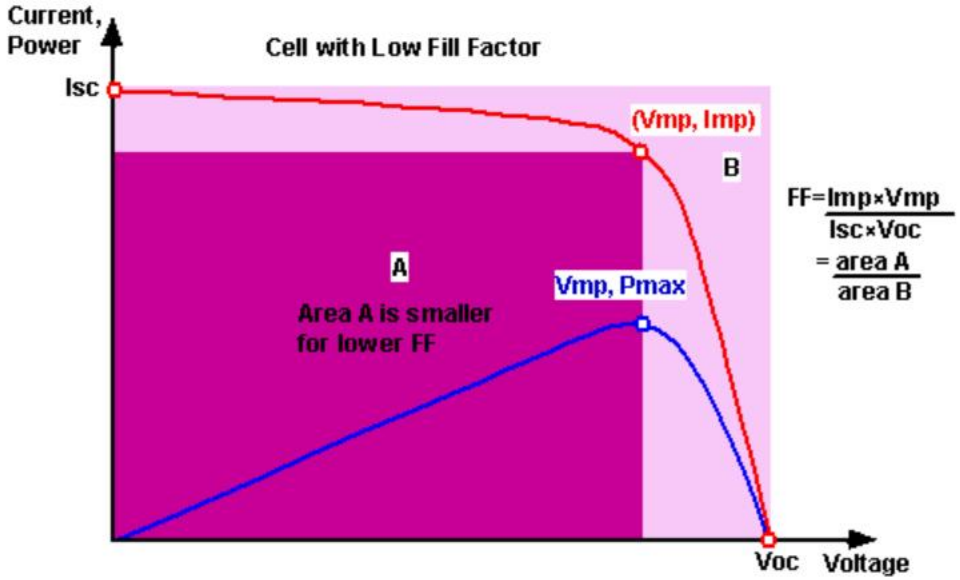
$$FF = \frac{V_{pm} \cdot I_{pm}}{V_{oc} \cdot I_{sc}}$$



- o masura a calitatii celulei
  - dependent de material

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





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

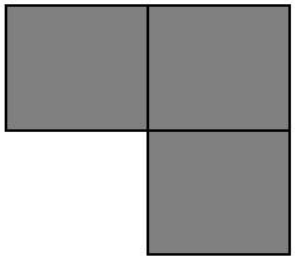
$$P_o = S \cdot \int_0^\infty \Phi_e(\lambda) d\lambda$$

Eficienta celulei solare

- determina suprafata necesara pentru obtinerea unei puteri dorite

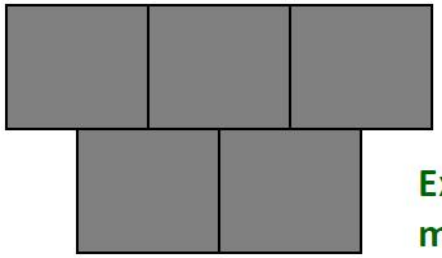
100% efficiency
(impossible to achieve)

33% efficiency
(space-grade solar cells)



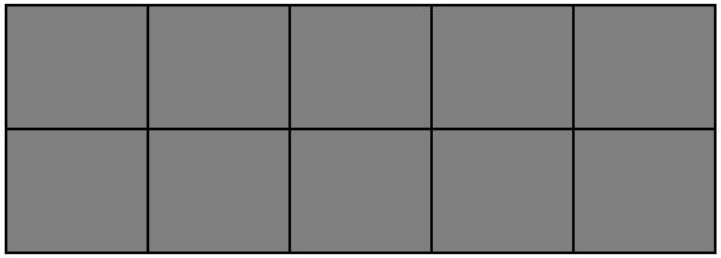
Very Expensive material

20% efficiency
(monocrystalline silicon solar cells)



Expensive material

10% efficiency
(thin film material)



Relatively Inexpensive material

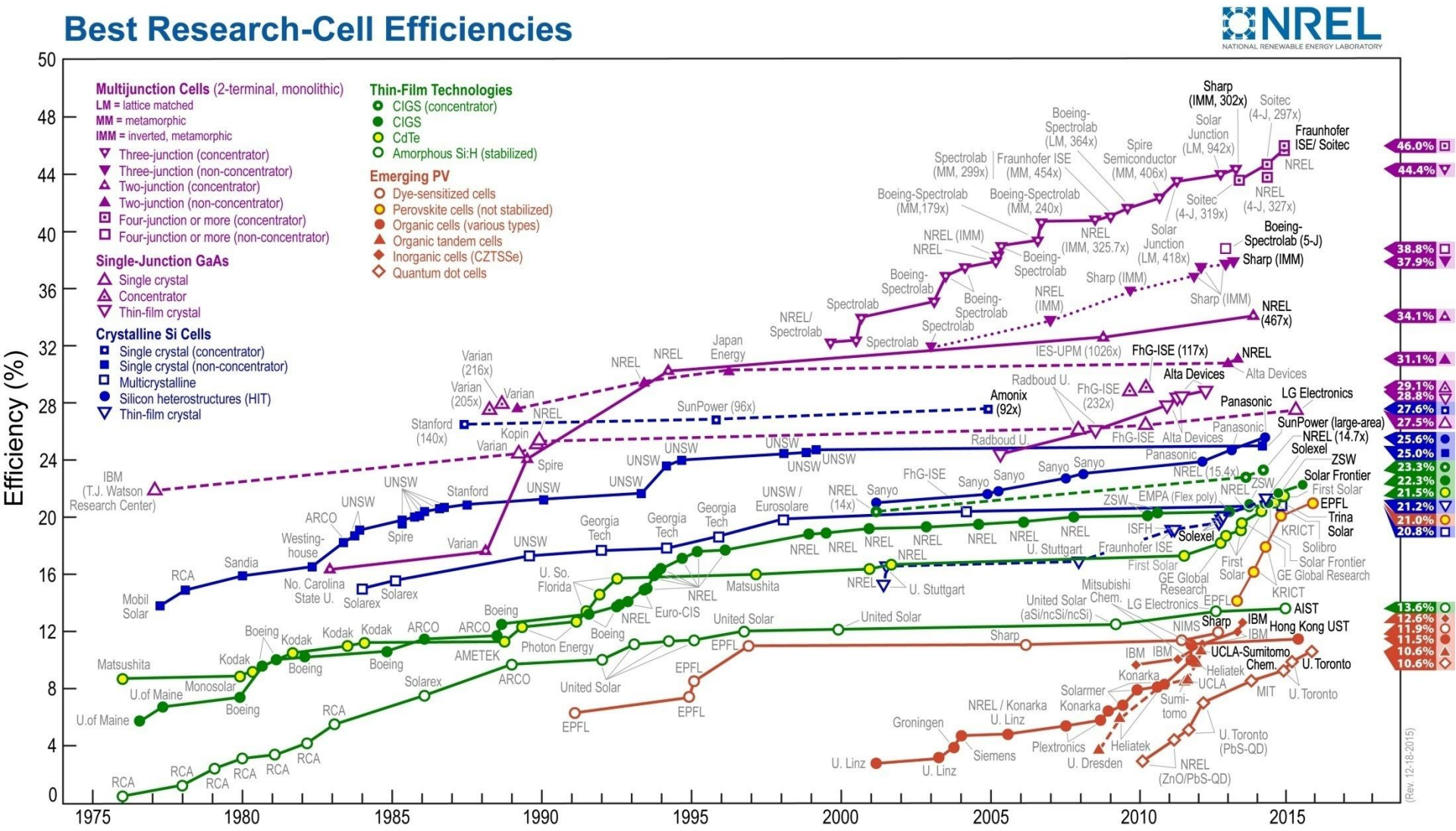
Eficienta celulei solare

- 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].

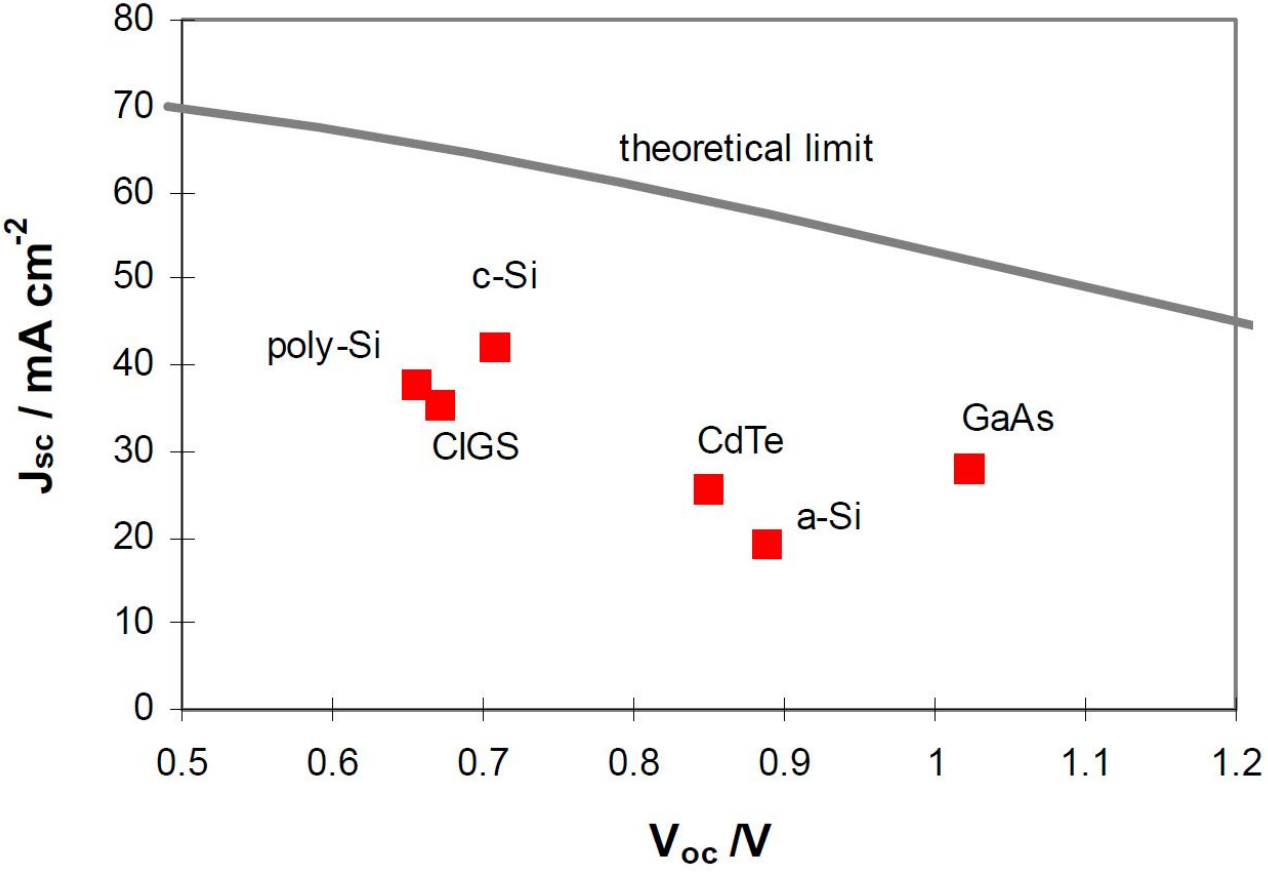
Cell Type	Area (cm^2)	V_{oc} (V)	J_{sc} (mA/cm^2)	FF	Efficiency (%)
crystalline Si	4.0	0.706	42.2	82.8	24.7
crystalline GaAs	3.9	1.022	28.2	87.1	25.1
poly-Si	1.1	0.654	38.1	79.5	19.8
a-Si	1.0	0.887	19.4	74.1	12.7
$CuInGaSe_2$	1.0	0.669	35.7	77.0	18.4
CdTe	1.1	0.848	25.9	74.5	16.4

Eficienta maxima a celulei solare



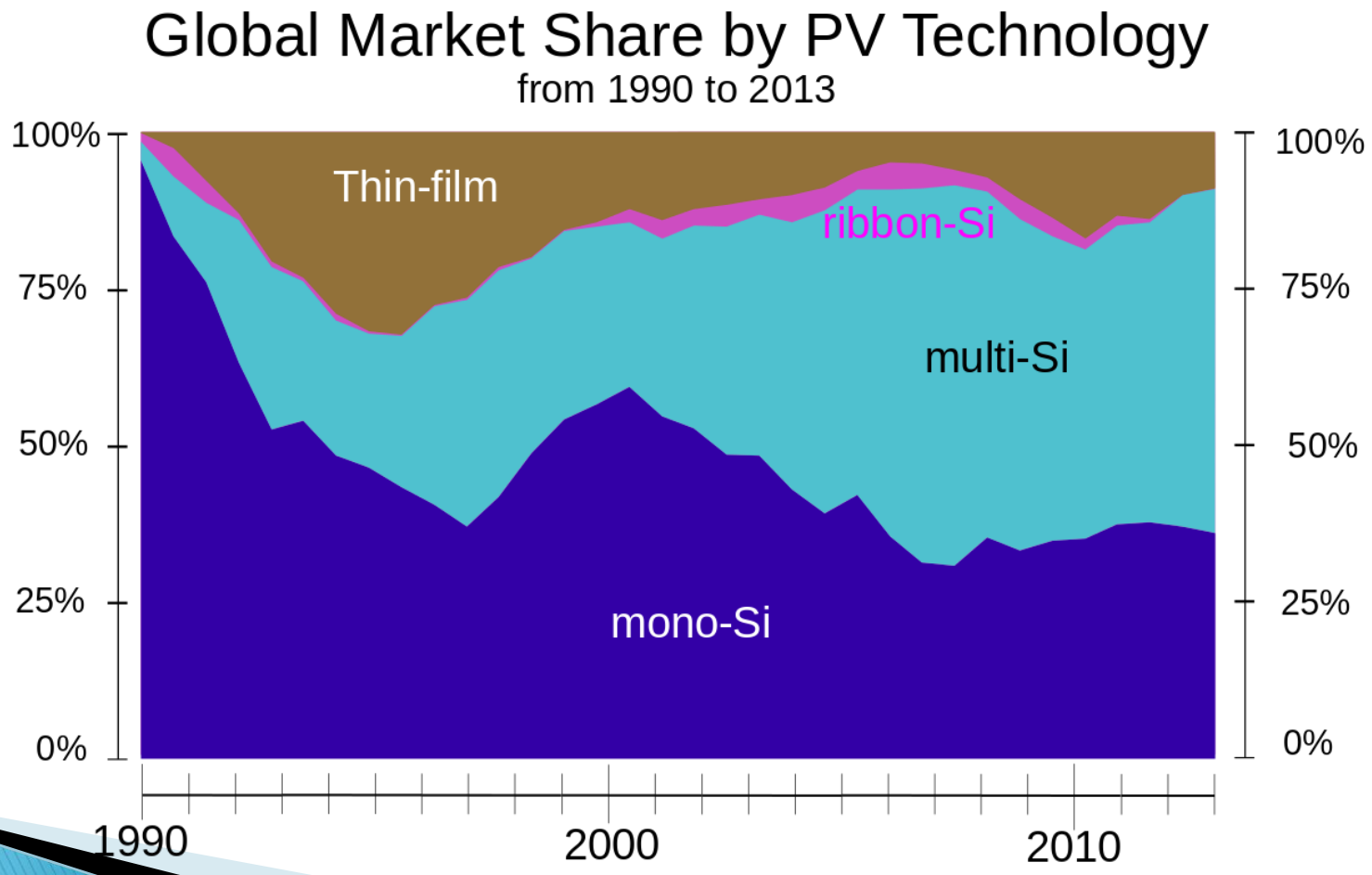
Dependenta de material

- 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

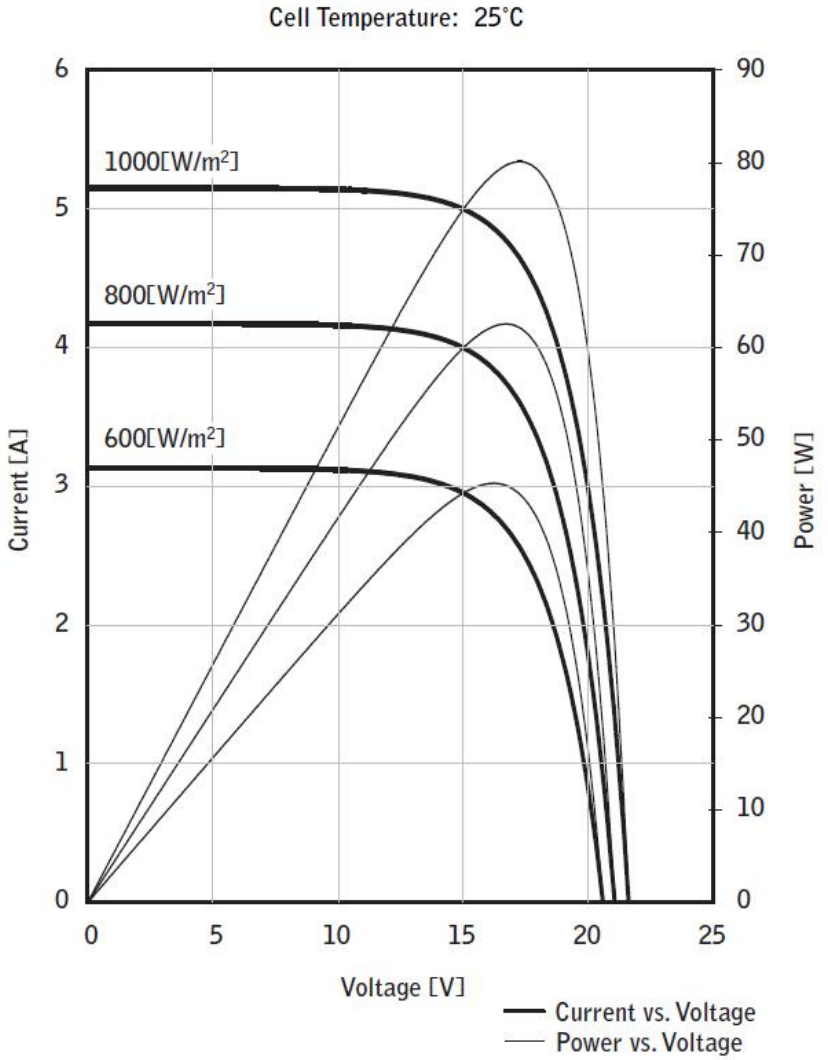
Sharp's NE-80EJEA photovoltaic modules offer industry-leading performance, durability, and reliability for a variety of electrical power requirements. Using breakthrough technology perfected by Sharp's 45 years of research and development, these modules incorporate an advanced surface texturing process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

Tipic

ELECTRICAL CHARACTERISTICS

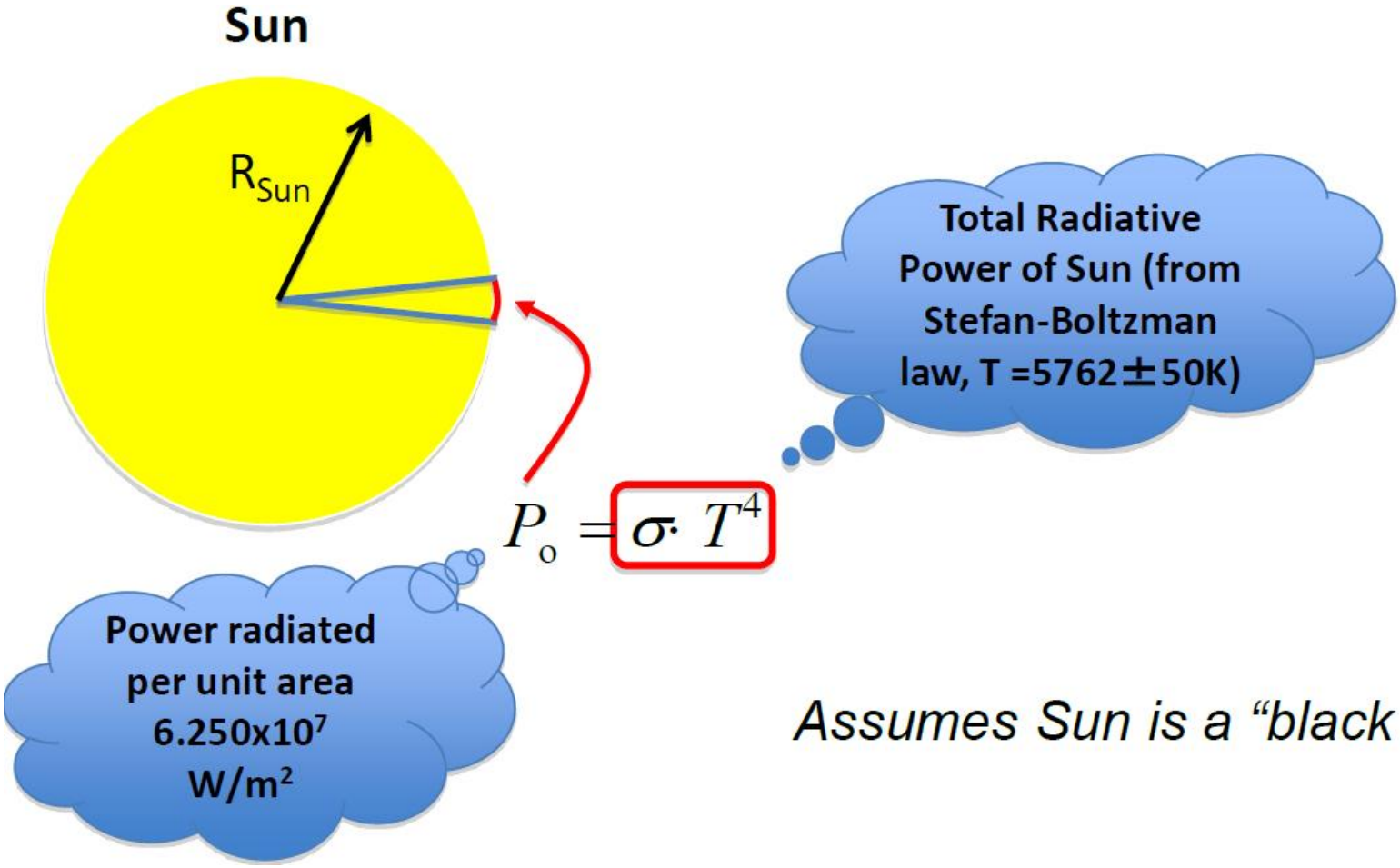
Cell	Poly-crystalline silicon
No. of Cells and Connections	36 in series
Open Circuit Voltage (Voc)	21.6V
Maximum Power Voltage (Vpm)	17.3V
Short Circuit Current (Isc)	5.16A
Maximum Power Current (Ipm)	4.63A
Maximum Power (Pmax)*	80W (+10% / -5%)
Module Efficiency (ηm)	12.40%
Maximum System Voltage	600VDC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

IV CURVES



Current, Power vs. Voltage Characteristics

Energia solara disponibila



Assumes Sun is a "black body."

Energia solara disponibila

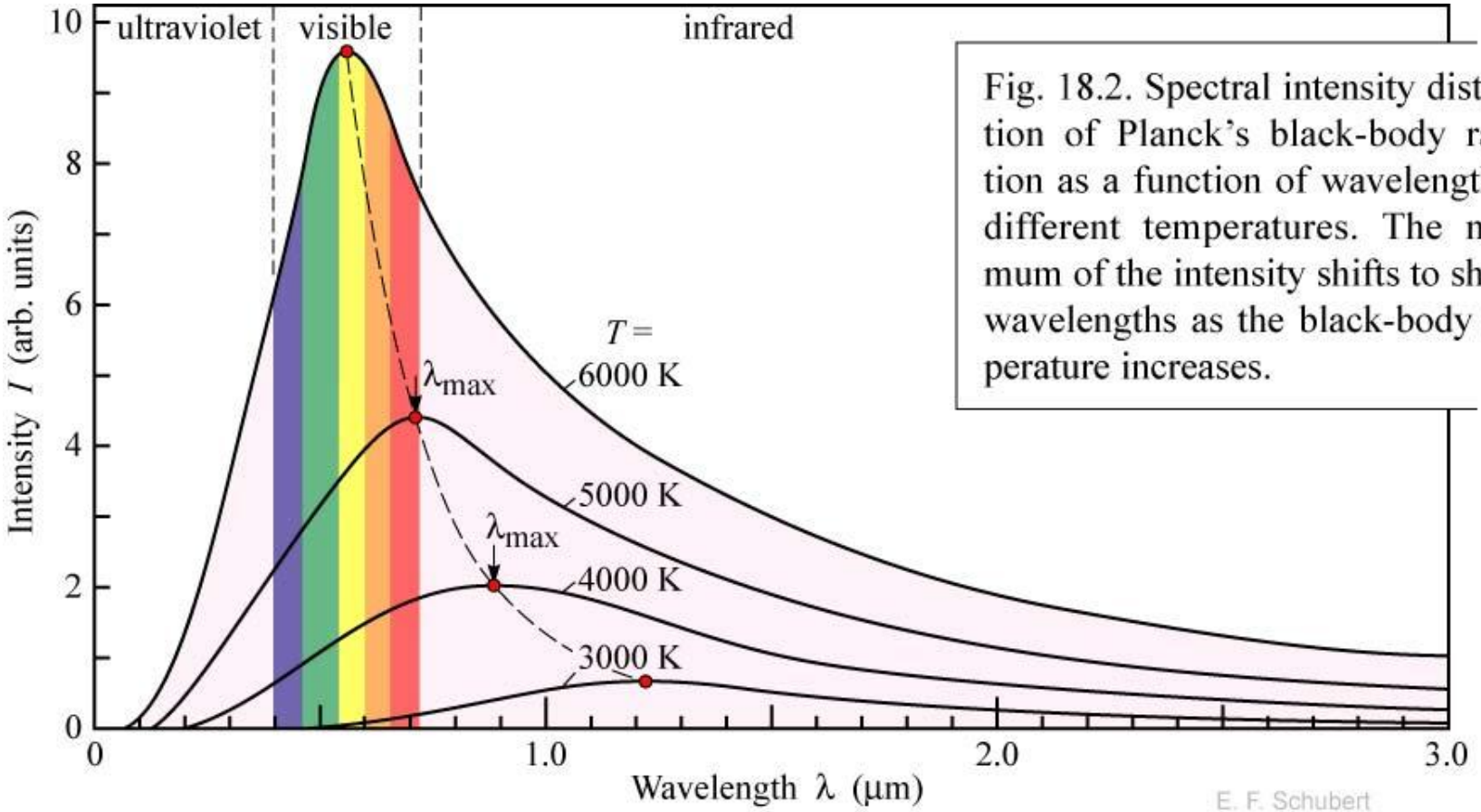
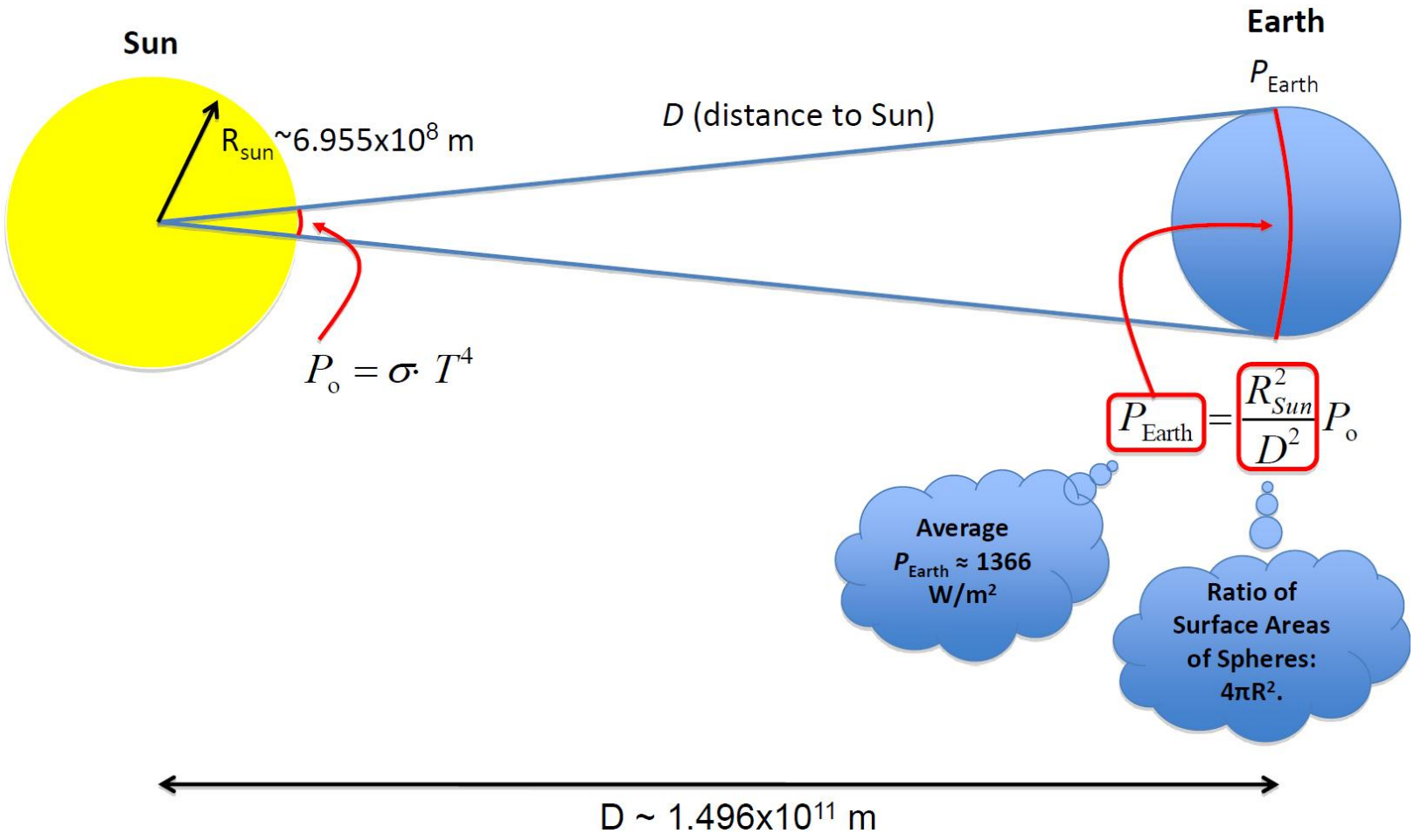
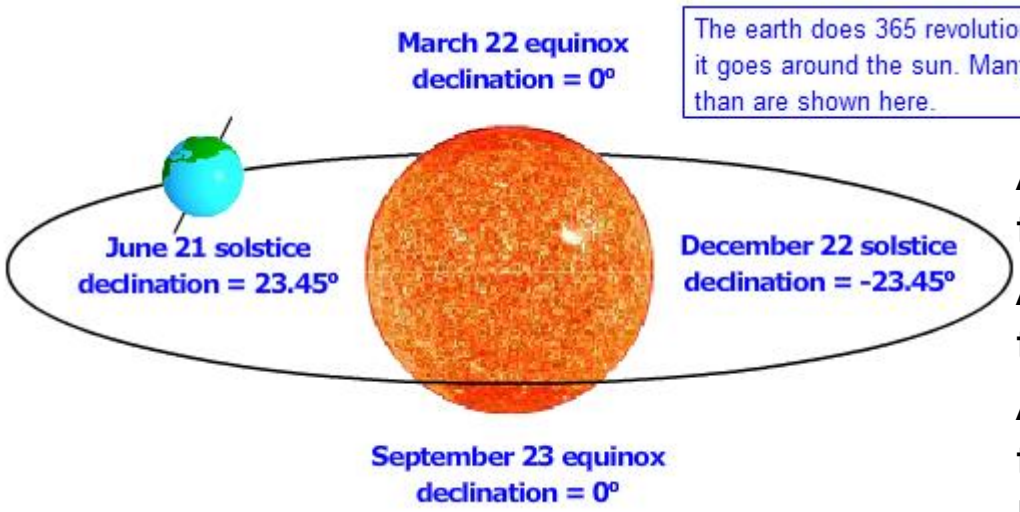


Fig. 18.2. Spectral intensity distribution of Planck's black-body radiation as a function of wavelength for different temperatures. The maximum of the intensity shifts to shorter wavelengths as the black-body temperature increases.

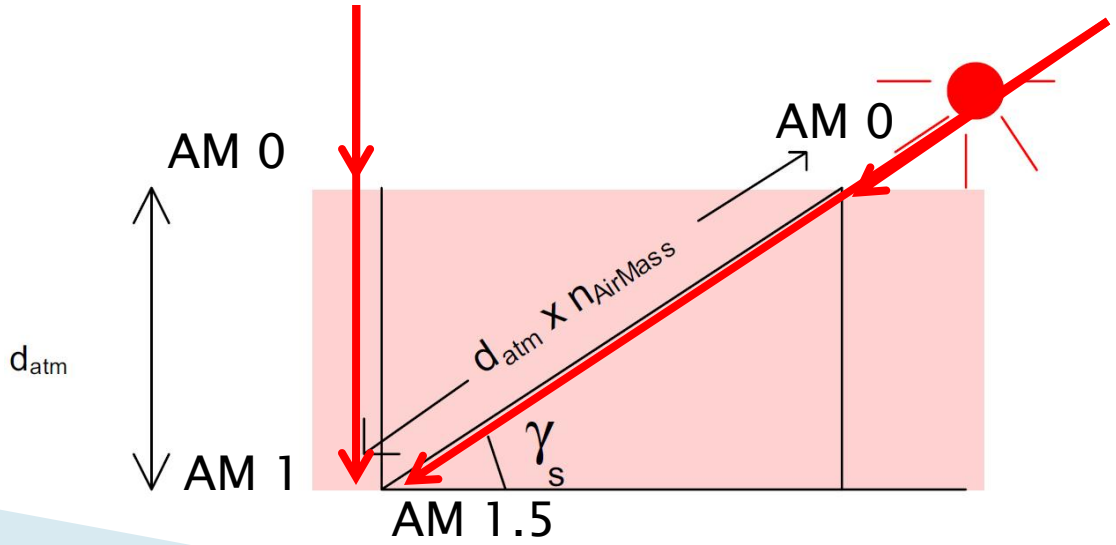
Energia solara disponibila



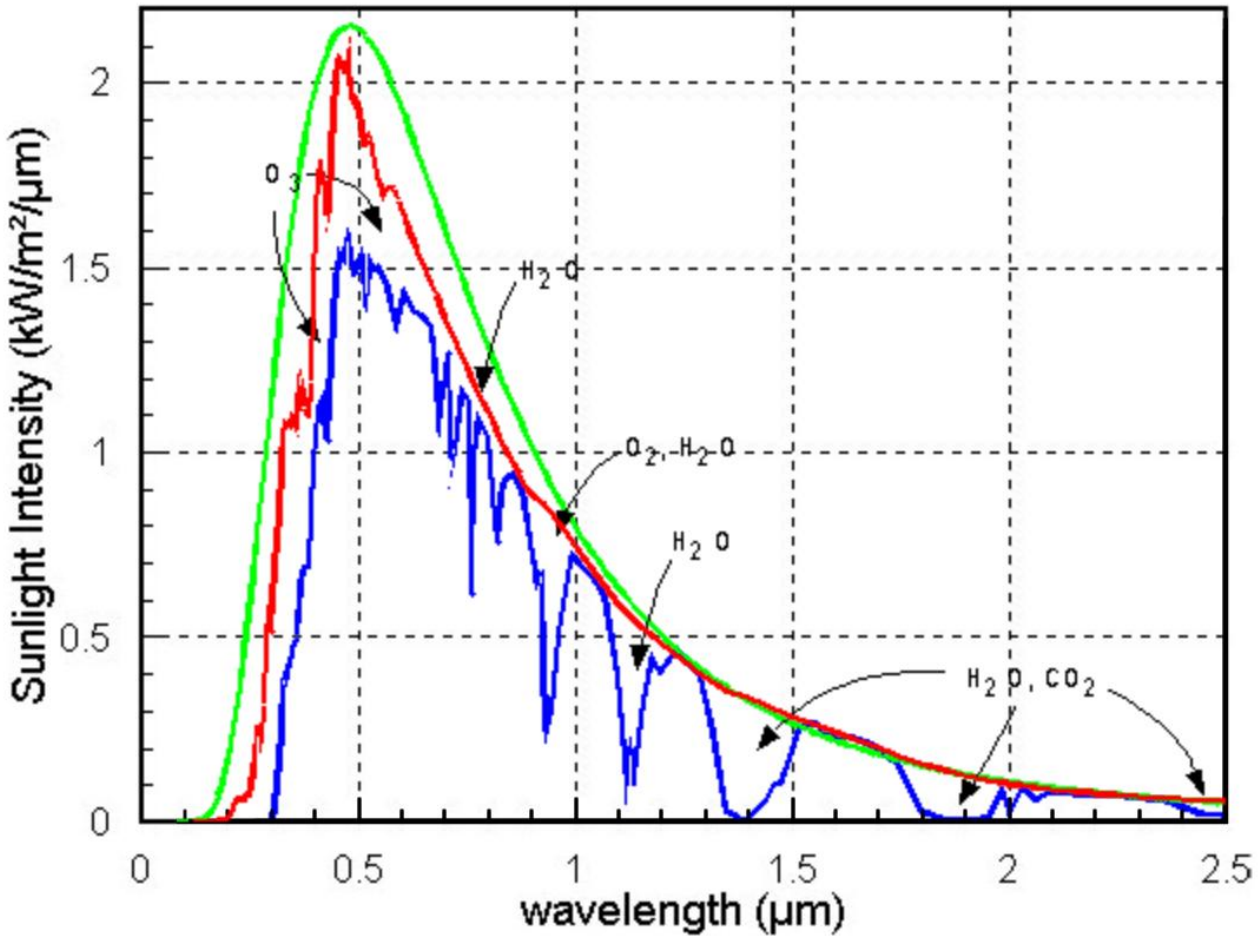
Energia solara disponibila



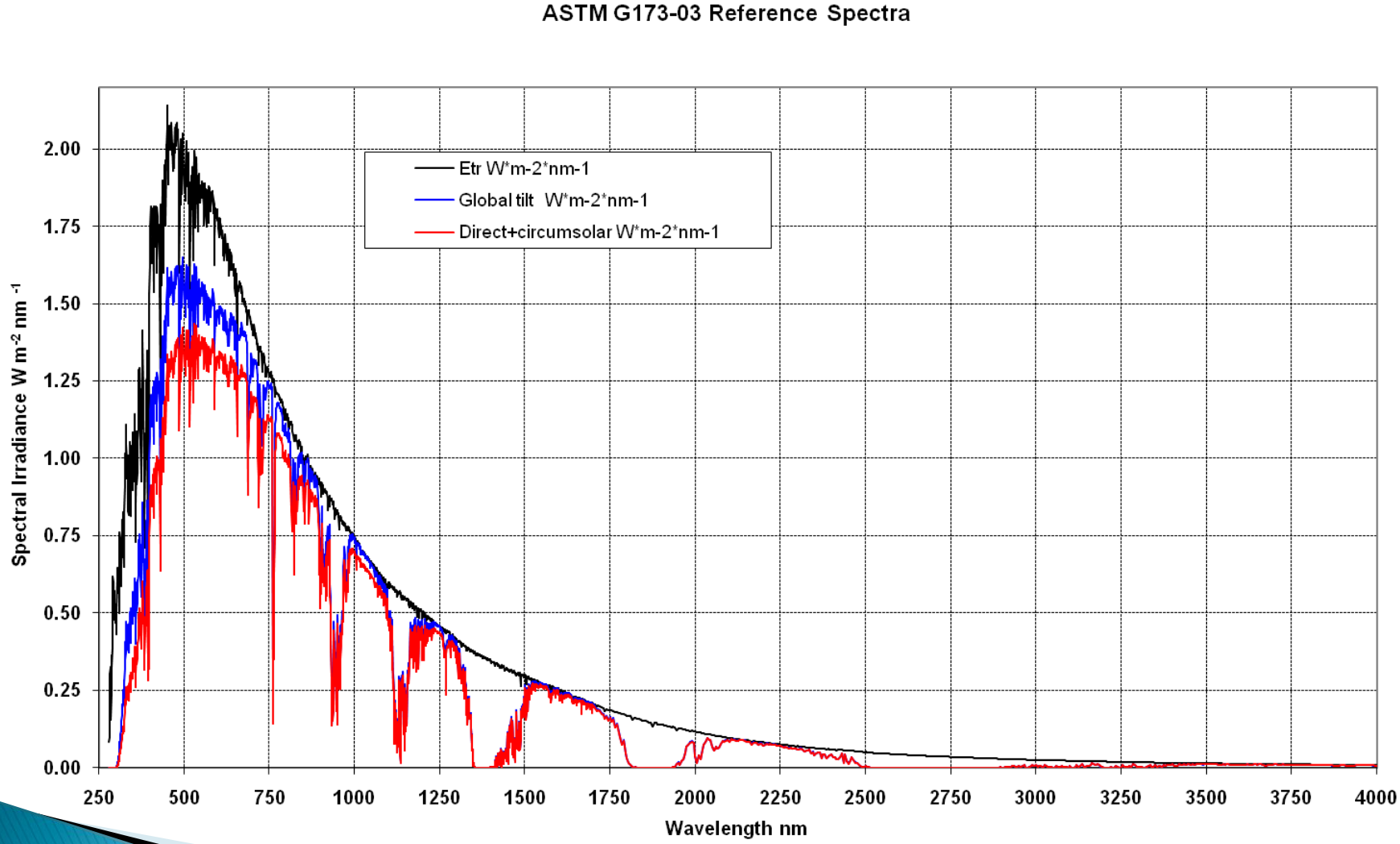
AM 0 = radiatia in afara atmosferei terestre
AM 1 = radiatia la suprafata terestra, incidenta normala
AM 1.5 = radiatia la suprafata terestra, incidenta corespunzatoare latitudinii de 48° (**standard**)



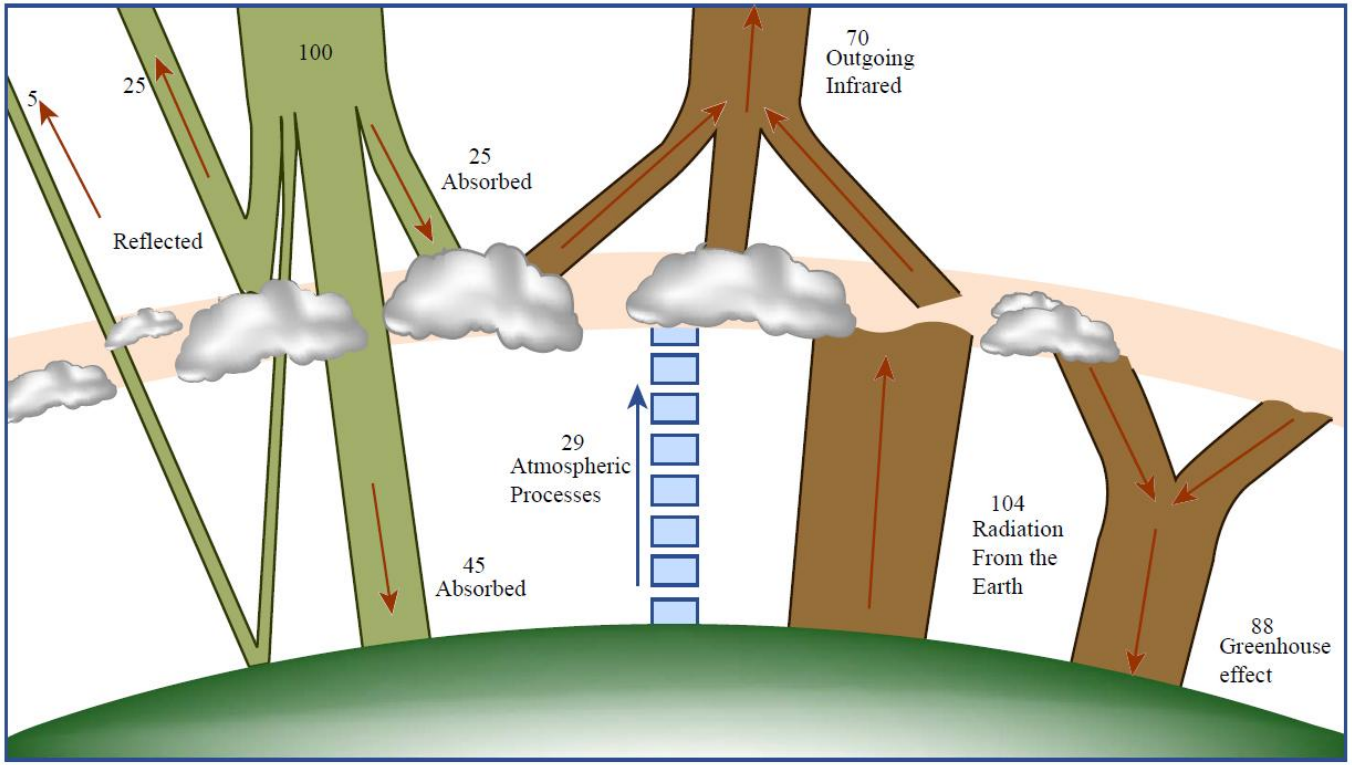
Energia solara disponibila



Energia solara disponibila



Energia solara disponibila

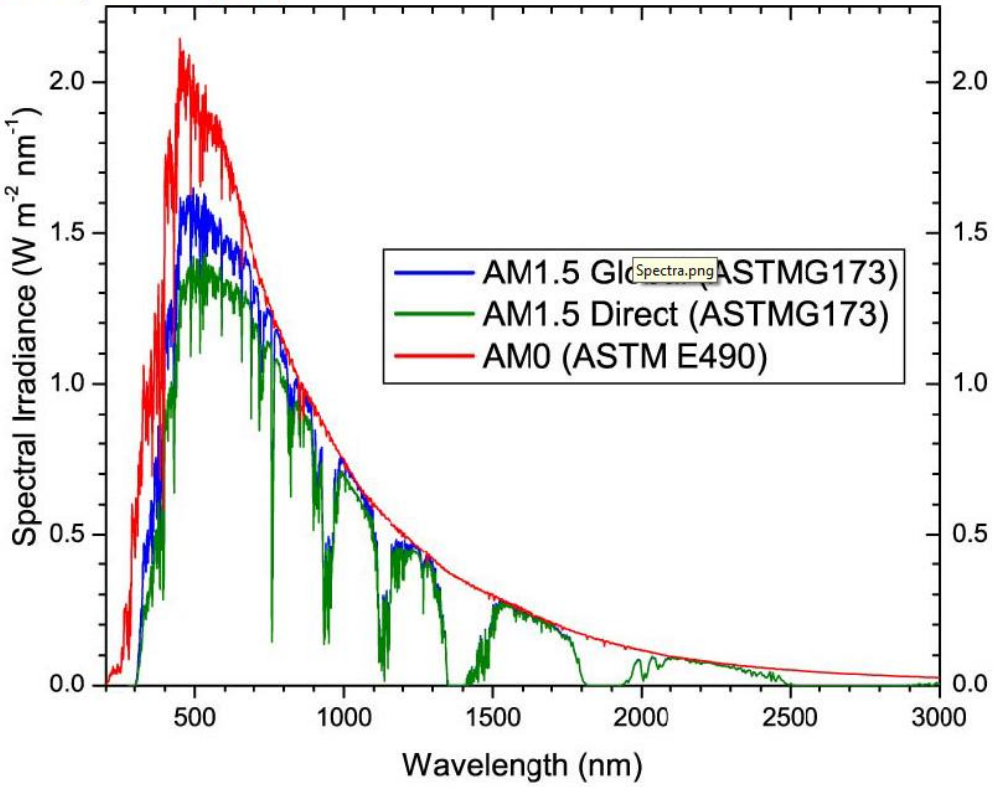


Heat trapping in the atmosphere dominates the earth's energy balance. Some 30% of incoming solar energy is reflected (left), either from clouds and particles in the atmosphere or from the earth's surface; the remaining 70% is absorbed. The absorbed energy is reemitted at infrared wavelengths by the atmosphere (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

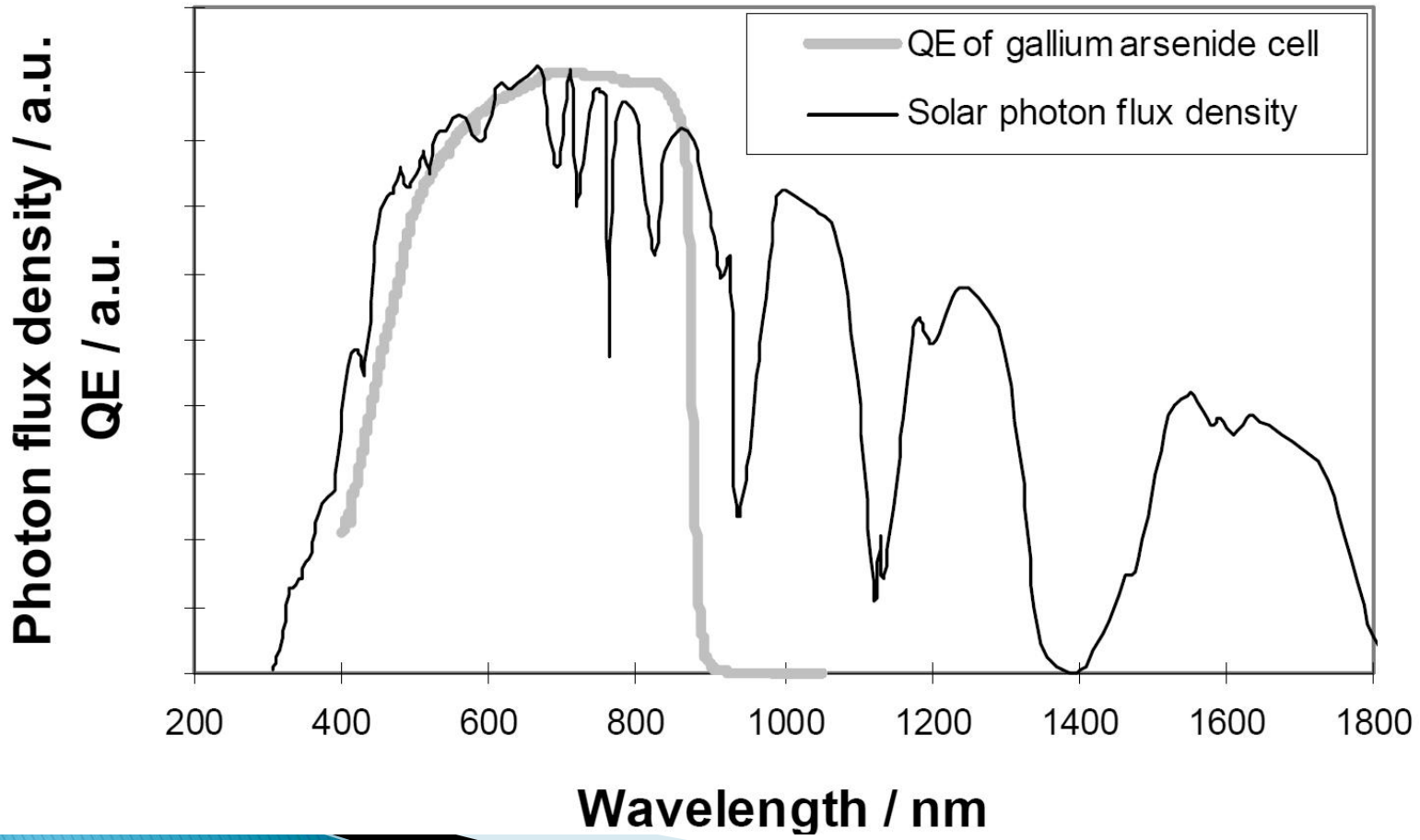
SOLAR SPECTRUM

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)

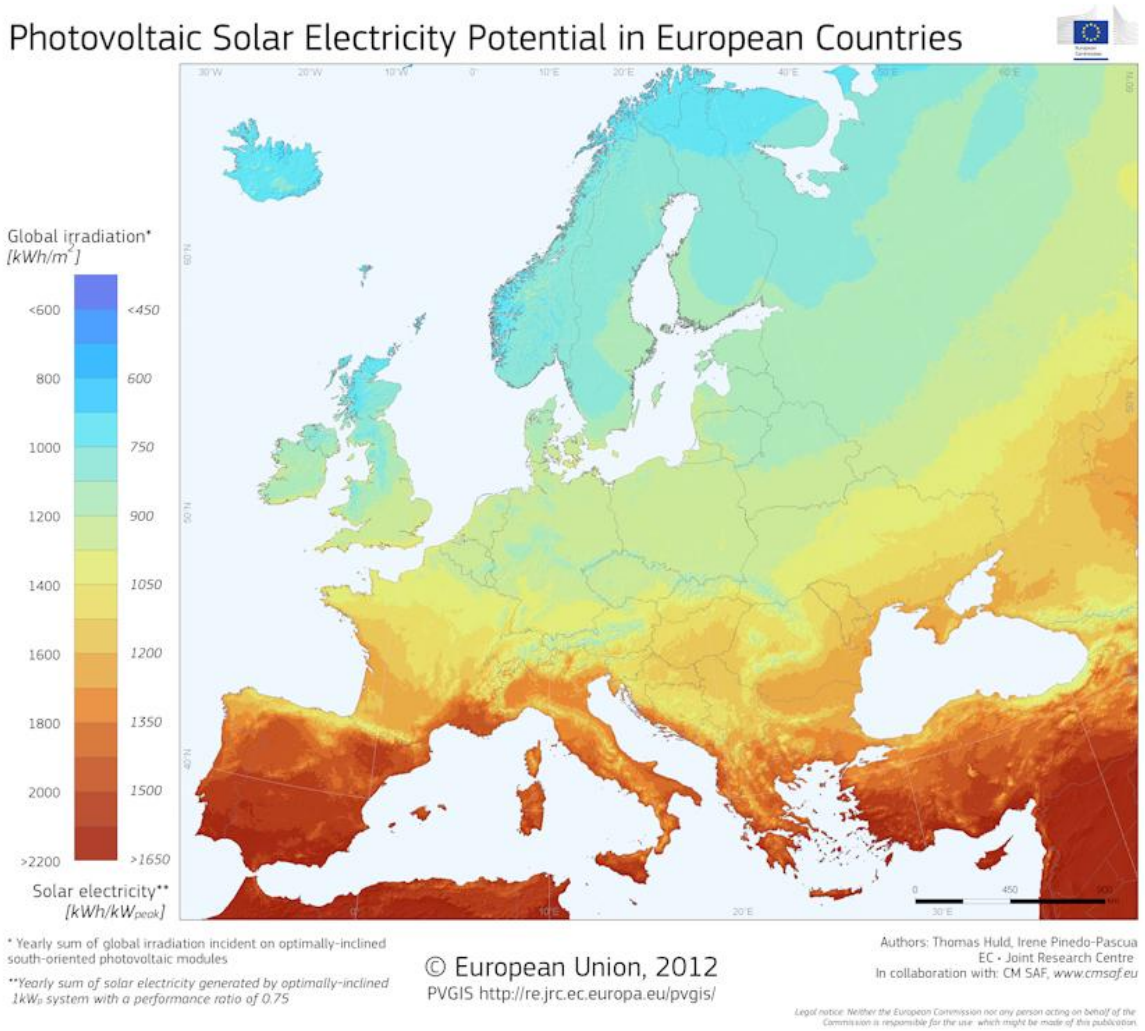


Motivatie eficienta limitata

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



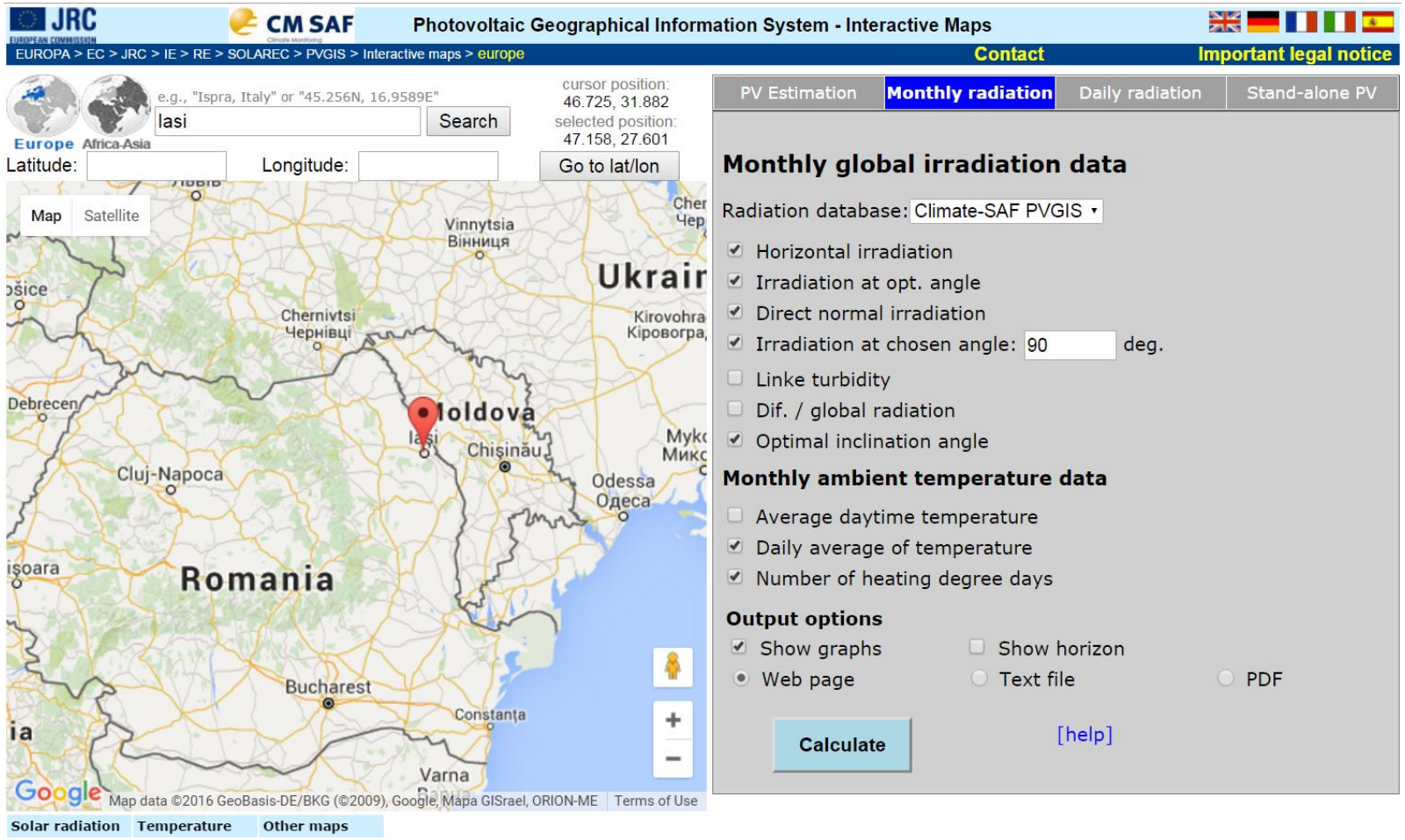
Energia solara disponibila



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

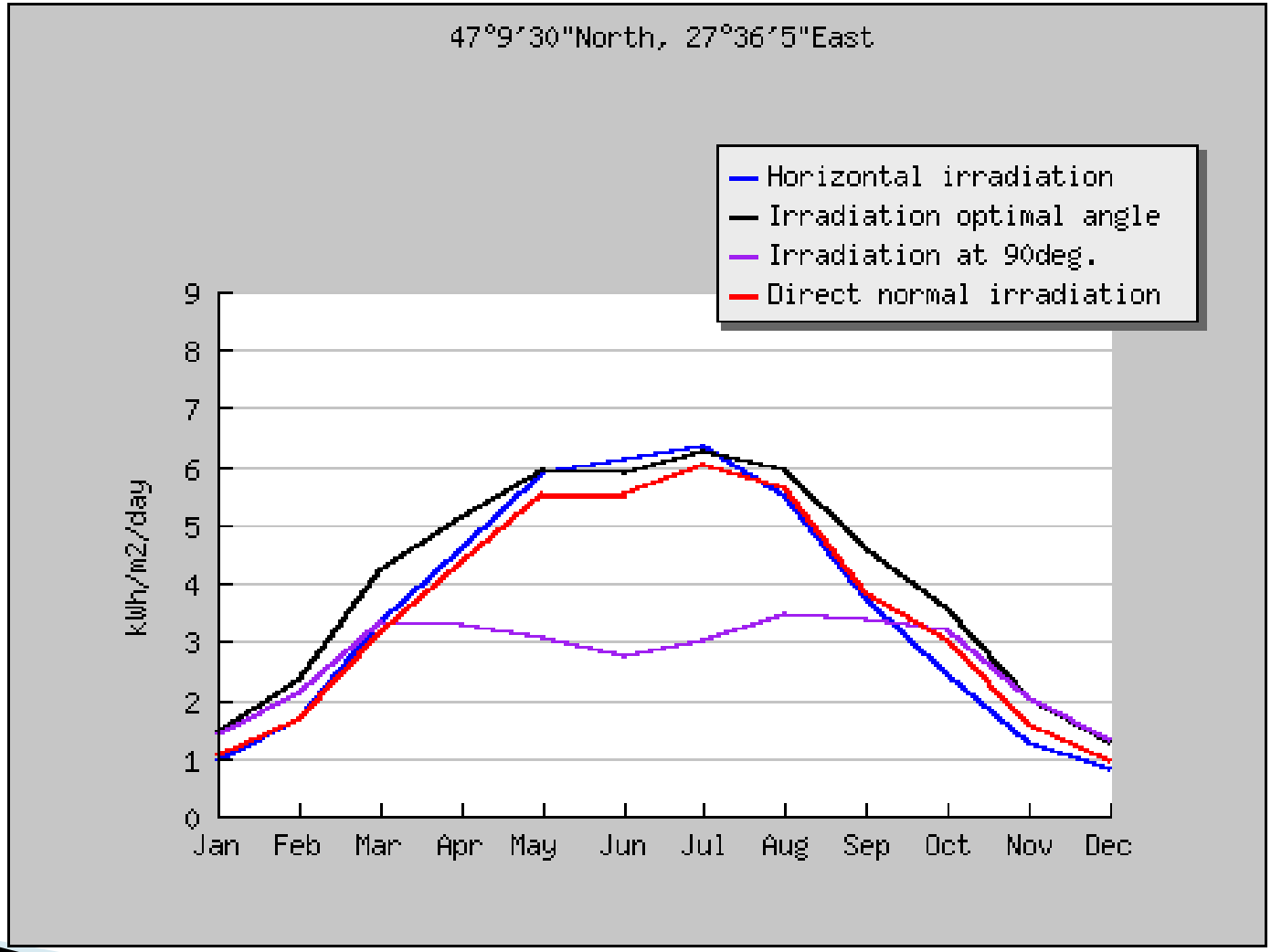
Energia solara disponibila

Energia solara disponibila

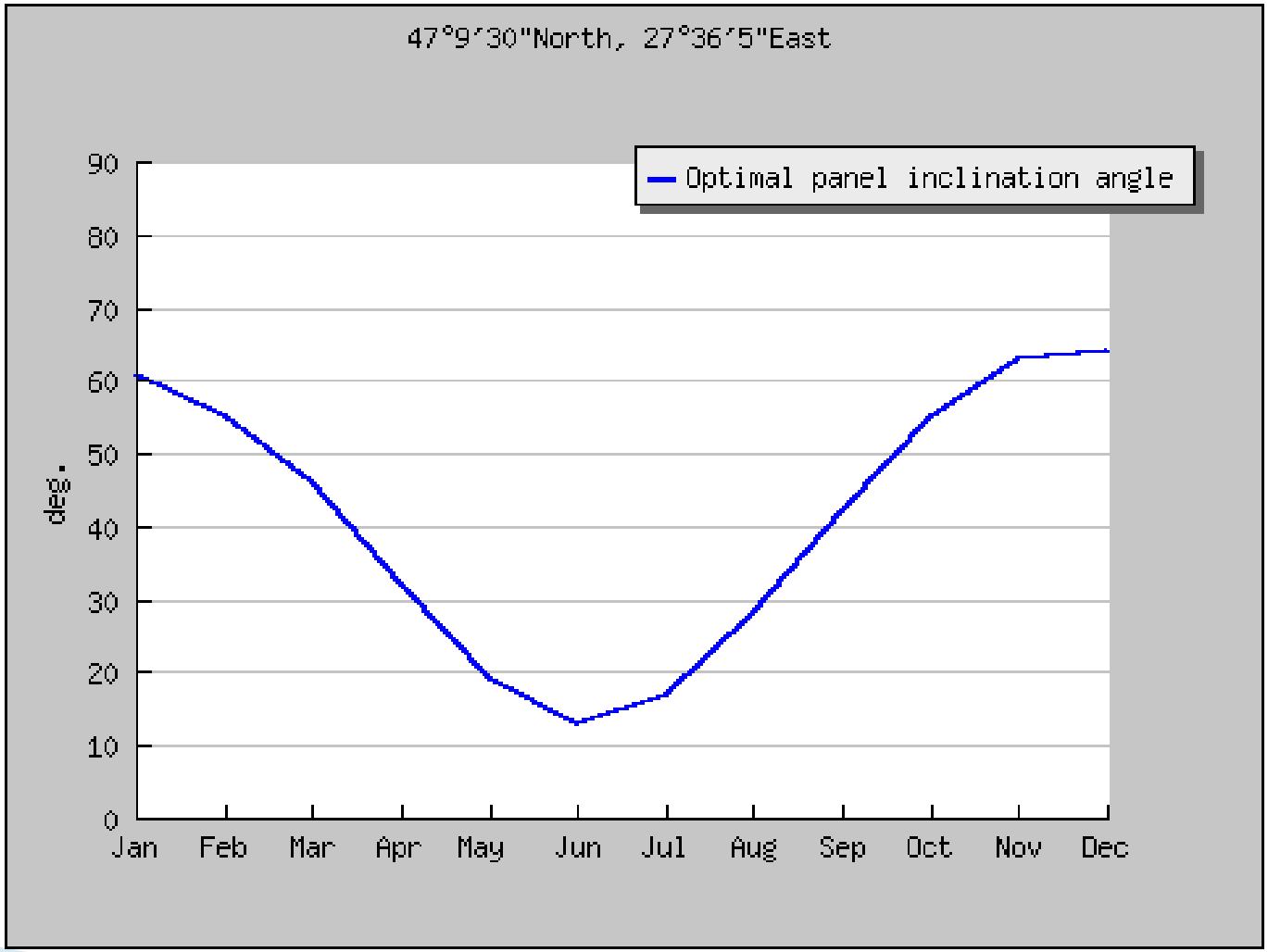


http://re.jrc.ec.europa.eu/pvgis/

Energia solara disponibila – Iasi



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

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
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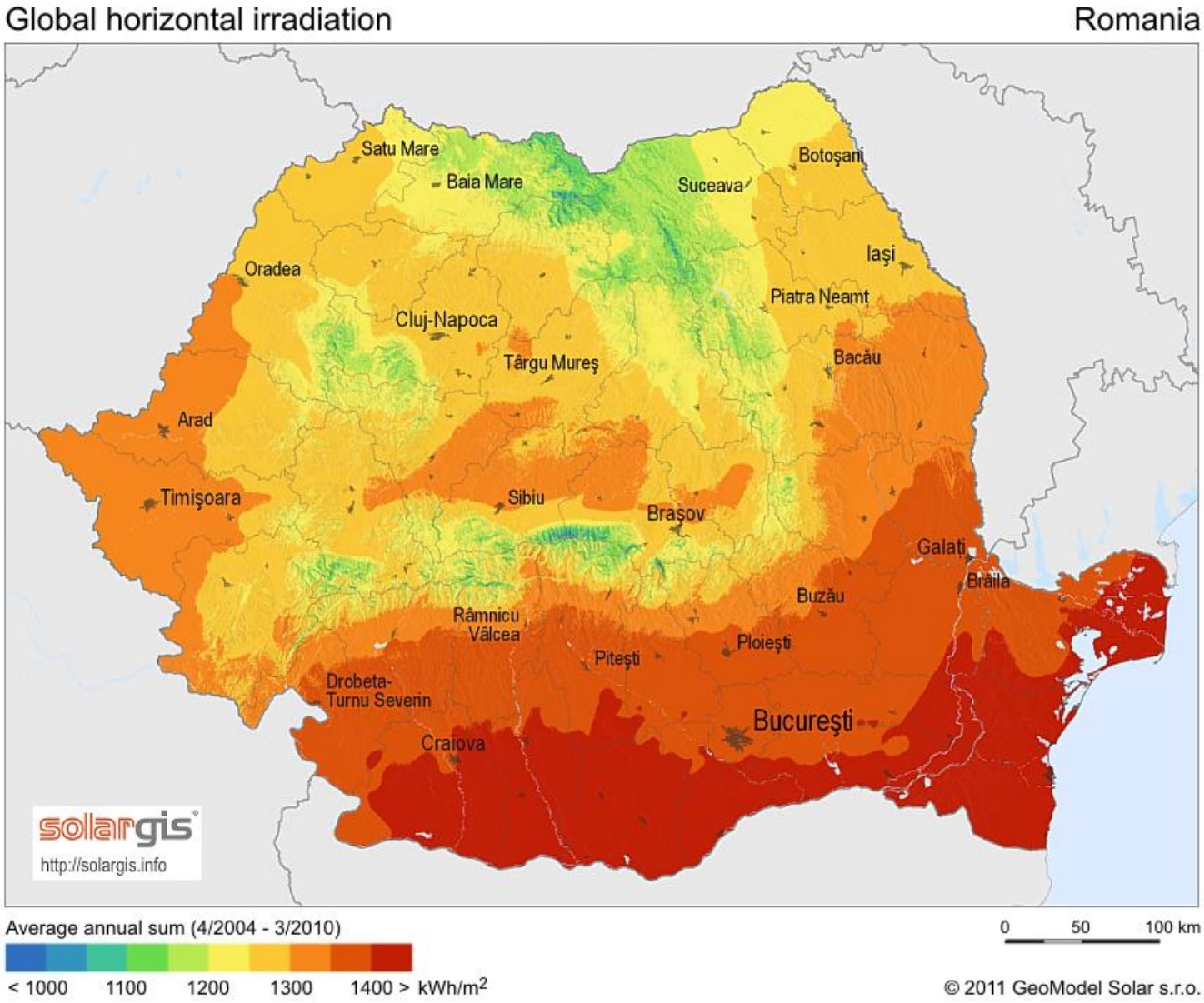
Oct	2450	3570	3210	3000	55	10.2
Nov	1260	2000	2010	1600	63	5.5
Dec	802	1280	1310	959	64	-0.8
Year	3560	4070	2700	3540	35	10.2

H_h: Irradiation on horizontal plane ($Wh/m^2/day$)
H_{opt}: Irradiation on optimally inclined plane ($Wh/m^2/day$)
H(90): Irradiation on plane at angle: 90deg. ($Wh/m^2/day$)
DNI: Direct normal irradiation ($Wh/m^2/day$)
I_{opt}: Optimal inclination (deg.)
T_{24h}: 24 hour average of temperature (°C)

Romania


Global horizontal irradiation
Romania
Satu Mare
Baia Mare
Suceava
Botoşani
Oradea
Iaşi
Piatra Neamt
Cluj-Napoca
Târgu Mureş
Bacău
Arad
Timişoara
Sibiu
Braşov
Galaţi
Brăila
Buzău
Râmnicu Vâlcea
Ploieşti
Piteşti
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.

Contact

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- http://rf-opto.etti.tuiasi.ro
- rdamian@etti.tuiasi.ro

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

- http://www.pveducation.org/