

Optoelectronică

Curs 12

2023/2024

Disciplina 2023/2024

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

Cuprins

- ▶ **Lumina ca undă electromagnetică*** (ecuațiile lui Maxwell, ecuația undelor, parametri de propagare)
- ▶ **Elemente de fotometrie și radiometrie*** (mărimi energetice/luminoase)
- ▶ **Fibra optică** (realizare, principiu de funcționare, atenuare, dispersie, banda de frecvență)
- ▶ **Cabluri optice** (tehnologie, conectori, lipire – splice)
- ▶ **Proiectare sistemică a legăturii pe fibra optică** (bandă de frecvență, balanța puterilor)
- ▶ **Emitătoare optice** (LED și dioda laser – realizare fizică și funcționare)
- ▶ **Receptoare optice** (dioda PIN, dioda cu avalanșă – realizare fizică și funcționare)
- ▶ **Amplificatoare transimpedanță** (parametri, scheme tipice, TIA în buclă deschisă, cu reacție, diferențiale, control automat al câștigului)
- ▶ **Realizarea circuitelor pentru controlul emițătoarelor optice** (parametri, scheme tipice, controlul puterii, multiplexoare)
- ▶ **Dispozitive de captare a energiei solare** (principiu de funcționare, utilizare, proiectare)

* – VP

Documentatie



[Main](#) [Courses](#) [Master](#) [Staff](#) [Research](#) [Students](#)

Microwave and Optoelectronics Laboratory

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

We currently cover inside ETIT the fields related to:

- Microwave Circuits and Devices
- Optoelectronics
- Information Technology

Courses

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



Documentatie

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

Emitătoare optice

LED/DL

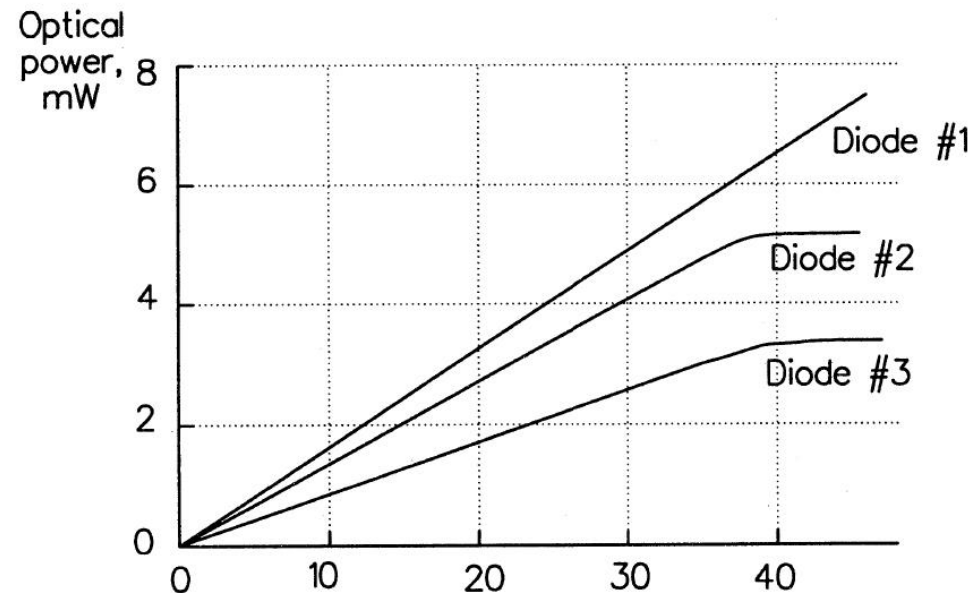
Caracteristica de raspuns a LED-urilor

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

- ▶ Responzivitatea

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

- ▶ Tipic $r = 50 \mu W / mA$



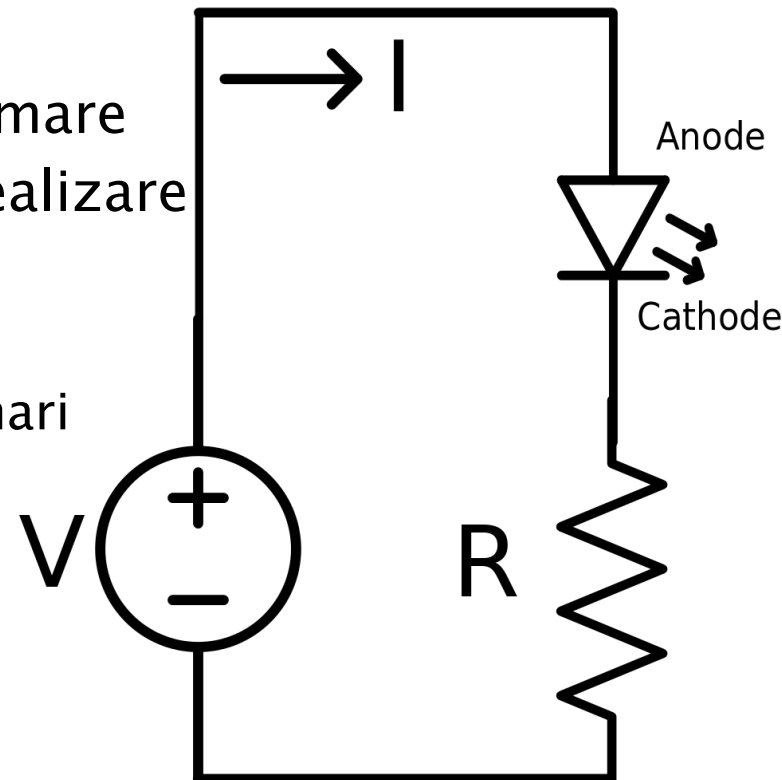
Control static LED

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

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

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

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



Caracteristica de raspuns DL

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

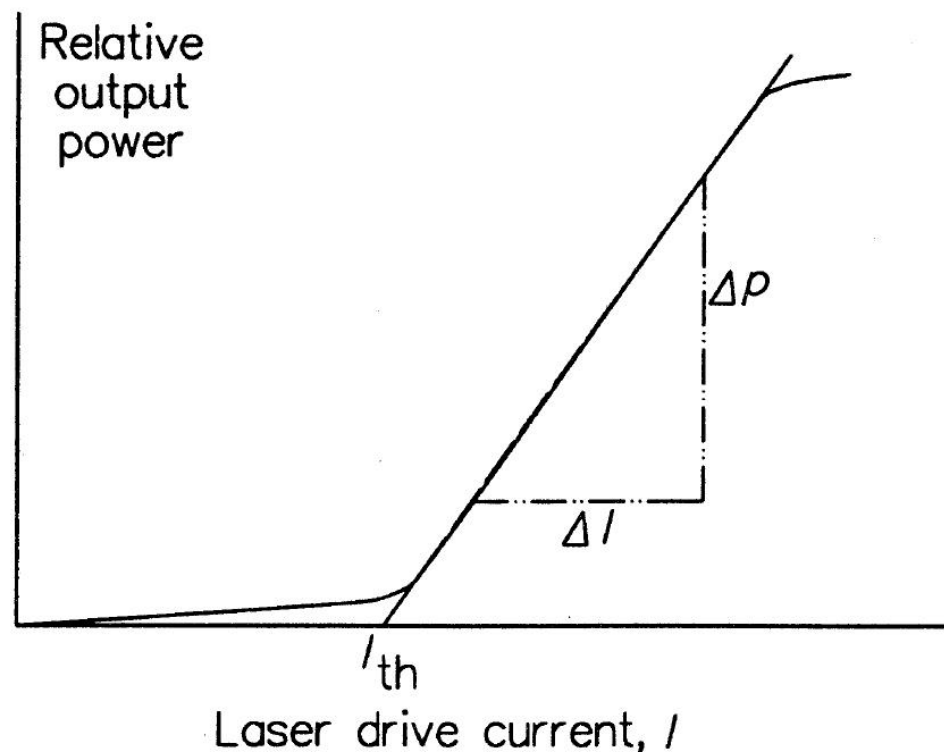
$I < I_{th}$ regim LED
ineficient!, $P_o \cong 0$

$I > I_{th}$ regim LASER

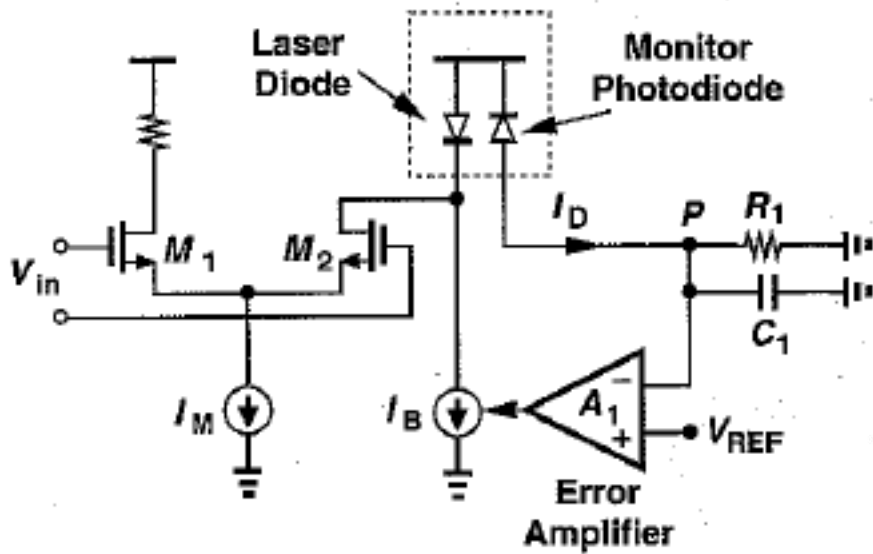
$$r = \frac{\Delta P_o}{\Delta I} \left[\frac{W}{A} \right]$$

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

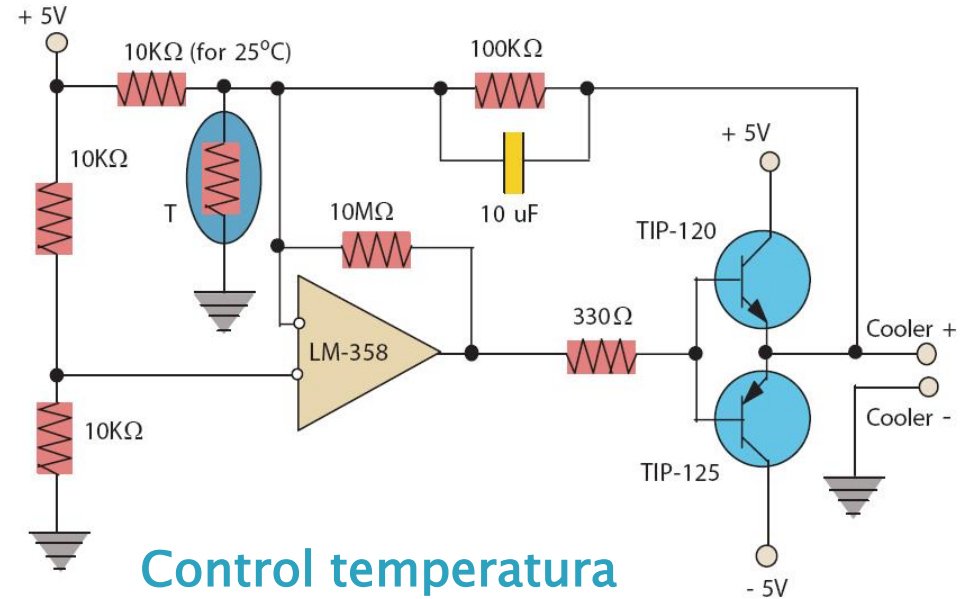
Apare saturare la nivele mari de curent



Control dioda LASER



Control putere optica



Control temperatura

Eficienta

- ▶ eficienta de conversie electro-optic (randament)

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

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

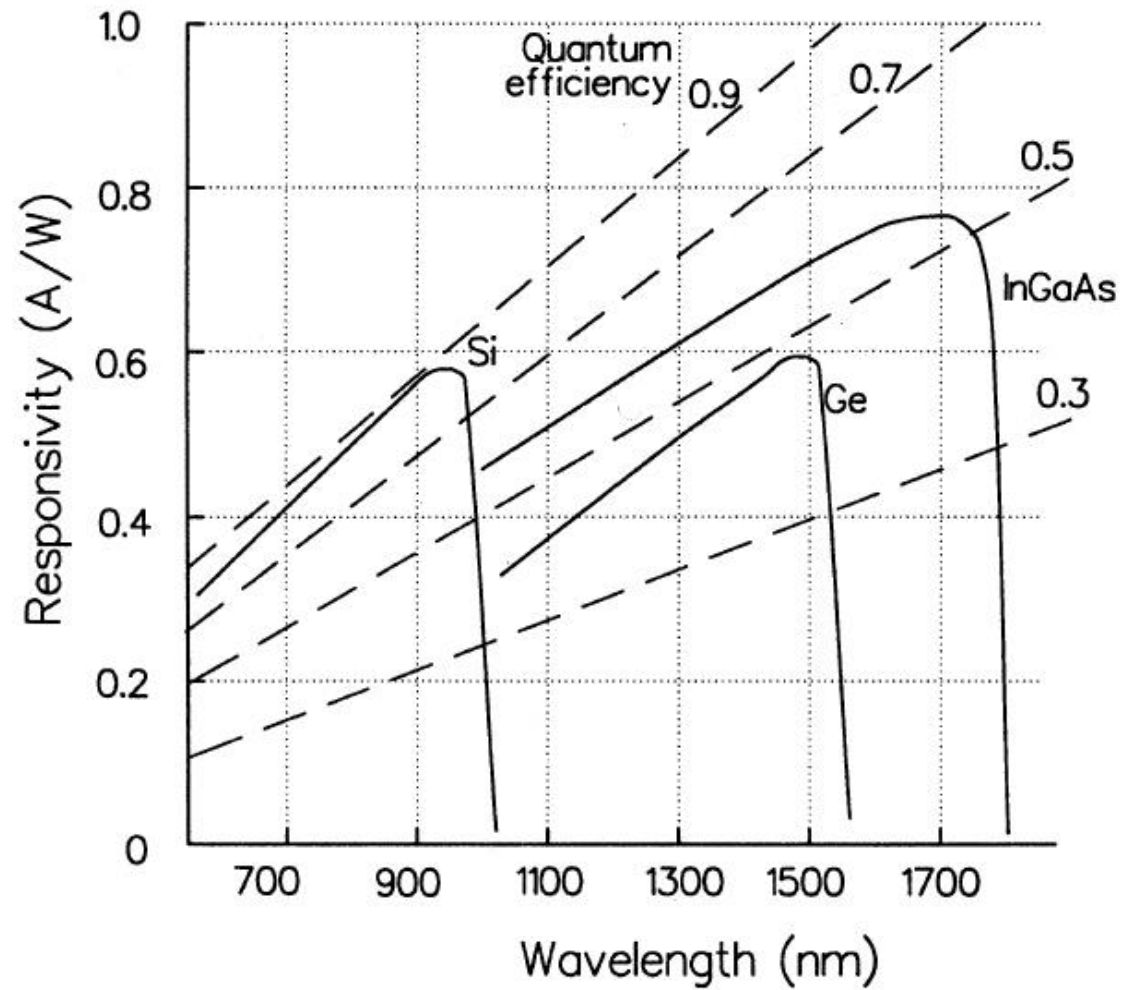
$$\eta = \frac{n_f}{n_e} \quad \eta = \frac{\Delta P / h\nu}{\Delta I / e} = r \cdot \frac{e}{h\nu}$$

Receptoare optice

Fotodioda

Fotodiode - marimi karakteristikke

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



Fotodioda – Marimi caracteristice

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

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

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

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

- ▶ Responzivitatea

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

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

Cuprins

- ▶ **Lumina ca undă electromagnetică** (ecuațiile lui Maxwell, ecuația undelor, parametri de propagare)
- ▶ **Elemente de fotometrie și radiometrie** (mărimi energetice/luminoase)
- ▶ **Fibra optică** (realizare, principiu de funcționare, atenuare, dispersie, banda de frecvență)
- ▶ **Cabluri optice** (tehnologie, conectori, lipire – splice)
- ▶ **Proiectare sistemică a legăturii pe fibra optică** (bandă de frecvență, balanța puterilor)
- ▶ **Emițătoare optice** (LED și dioda laser – realizare fizică și funcționare)
- ▶ **Receptoare optice** (dioda PIN, dioda cu avalanșă – realizare fizică și funcționare)
- ▶ **Amplificatoare transimpedanță** (parametri, scheme tipice, TIA în buclă deschisă, cu reacție, diferențiale, control automat al câștigului)
- ▶ **Realizarea circuitelor pentru controlul emițătoarelor optice** (parametri, scheme tipice, controlul puterii, multiplexoare)
- ▶ **Dispozitive de captare a energiei solare** (principiu de funcționare, utilizare, proiectare)

Documentatie

- ▶ Behzad Razavi – Design of Integrated Circuits for Optical Communications

Textbooks

[IBM Redbooks - Understanding Optical Communications](#) (pdf, 5.24 MB, en, )

[Behzad Razavi - Design of Integrated Circuits for Optical Communications](#) (pdf, 11.18 MB, en, )

[John Powers - An Introduction to Fiber Optic Systems](#) (pdf, 50.54 MB, en, )

[Stefan Nilsson-Gistvik - Optical Fiber Theory for Communication Networks](#) (pdf, 17.62 MB, en, )

[Structuri Optoelectronice](#) (pdf, 3.13 MB, ro, )

[MIT Course - Fundamentals of Photovoltaics](#) (link, 0 Bytes, en, )

[EU Photovoltaic Geographical Information System \(PVGIS\)](#) (link, 0 Bytes, en, )

Utilizare celule solare

Capitolul 10

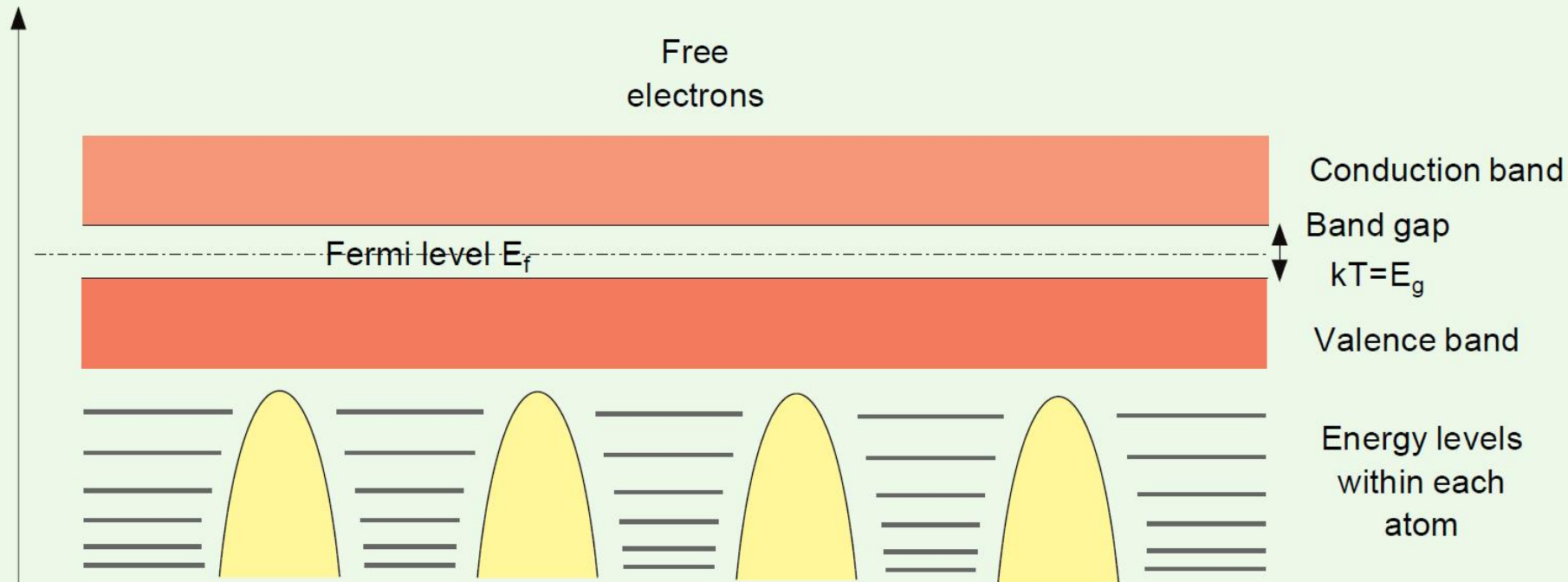
Cuprins

- ▶ **Lumina ca undă electromagnetică** (ecuațiile lui Maxwell, ecuația undelor, parametri de propagare)
- ▶ **Elemente de fotometrie și radiometrie** (mărimi energetice/luminoase)
- ▶ **Fibra optică** (realizare, principiu de funcționare, atenuare, dispersie, banda de frecvență)
- ▶ **Cabluri optice** (tehnologie, conectori, lipire – splice)
- ▶ **Proiectare sistemică a legăturii pe fibra optică** (bandă de frecvență, balanța puterilor)
- ▶ **Emițătoare optice** (LED și dioda laser – realizare fizică și funcționare)
- ▶ **Receptoare optice** (dioda PIN, dioda cu avalanșă – realizare fizică și funcționare)
- ▶ **Amplificatoare transimpedanță** (parametri, scheme tipice, TIA în buclă deschisă, cu reacție, diferențiale, control automat al câștigului)
- ▶ **Realizarea circuitelor pentru controlul emițătoarelor optice** (parametri, scheme tipice, controlul puterii, multiplexoare)
- ▶ **Dispozitive de captare a energiei solare** (principiu de funcționare, utilizare, proiectare)

Efect fotovoltaic

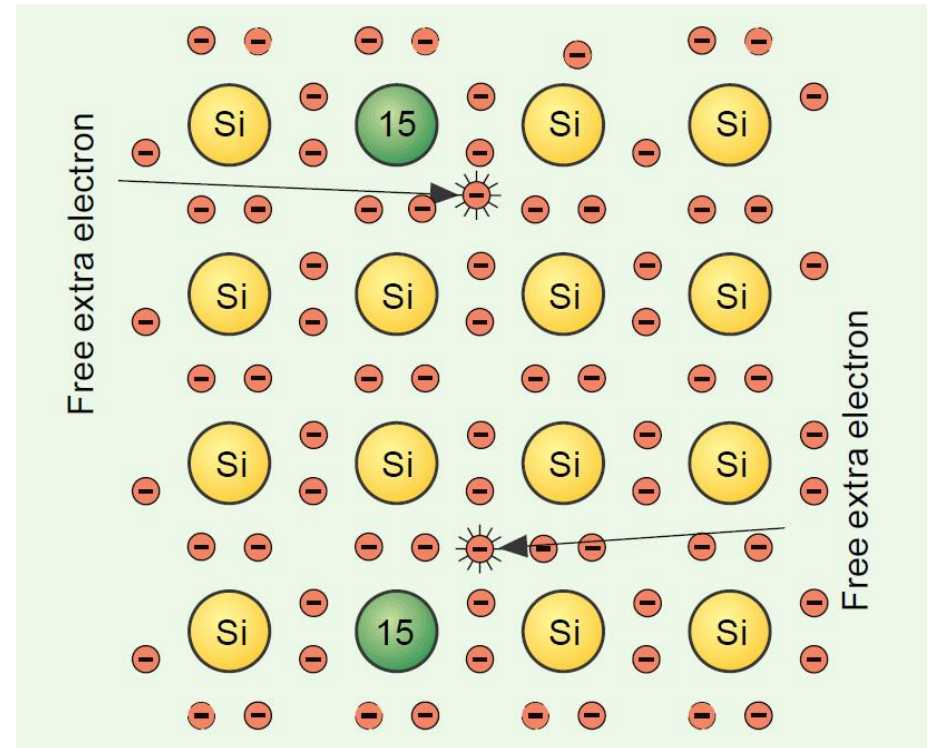
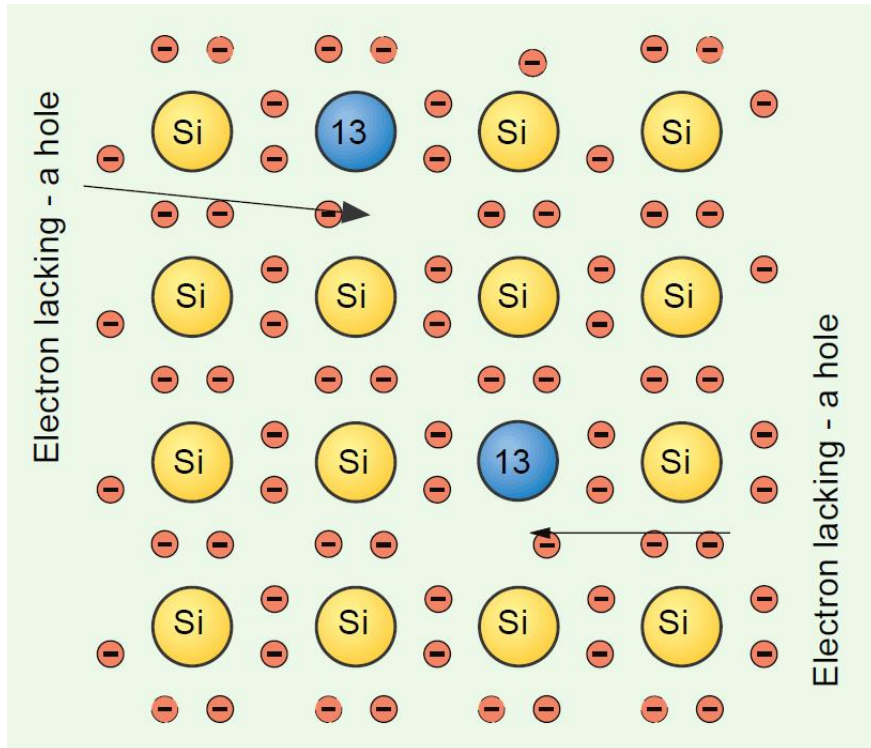
▶ joncțiunea pn

Energy level



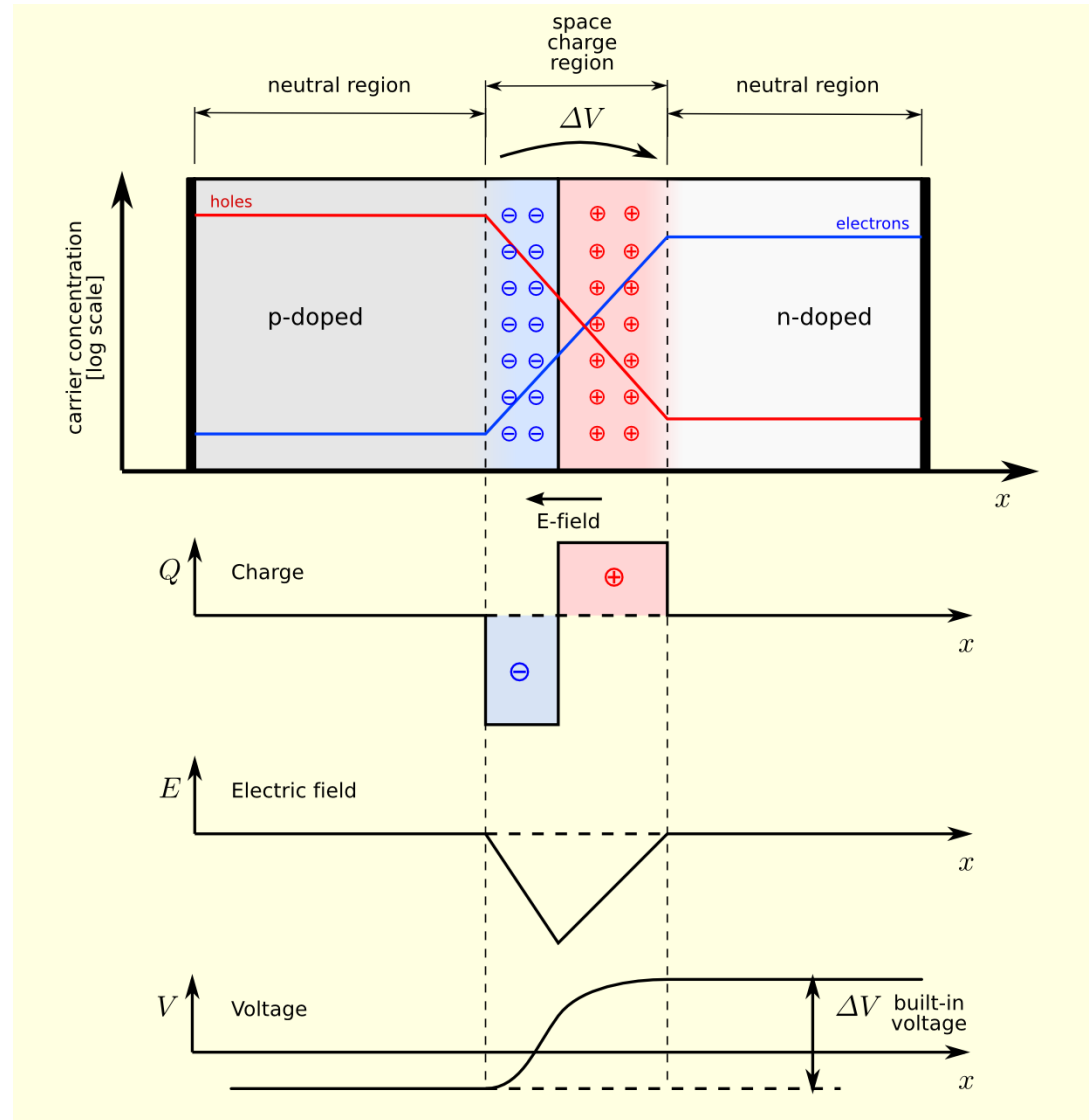
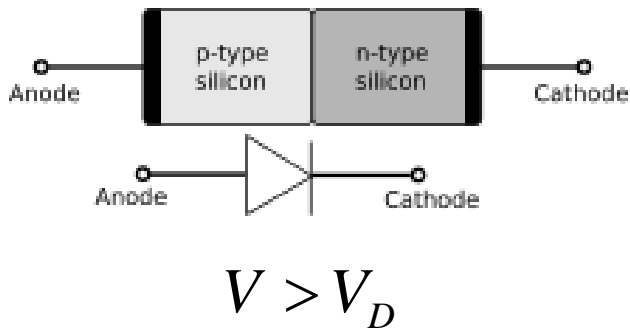
Efect fotovoltaic

▶ joncțiunea pn



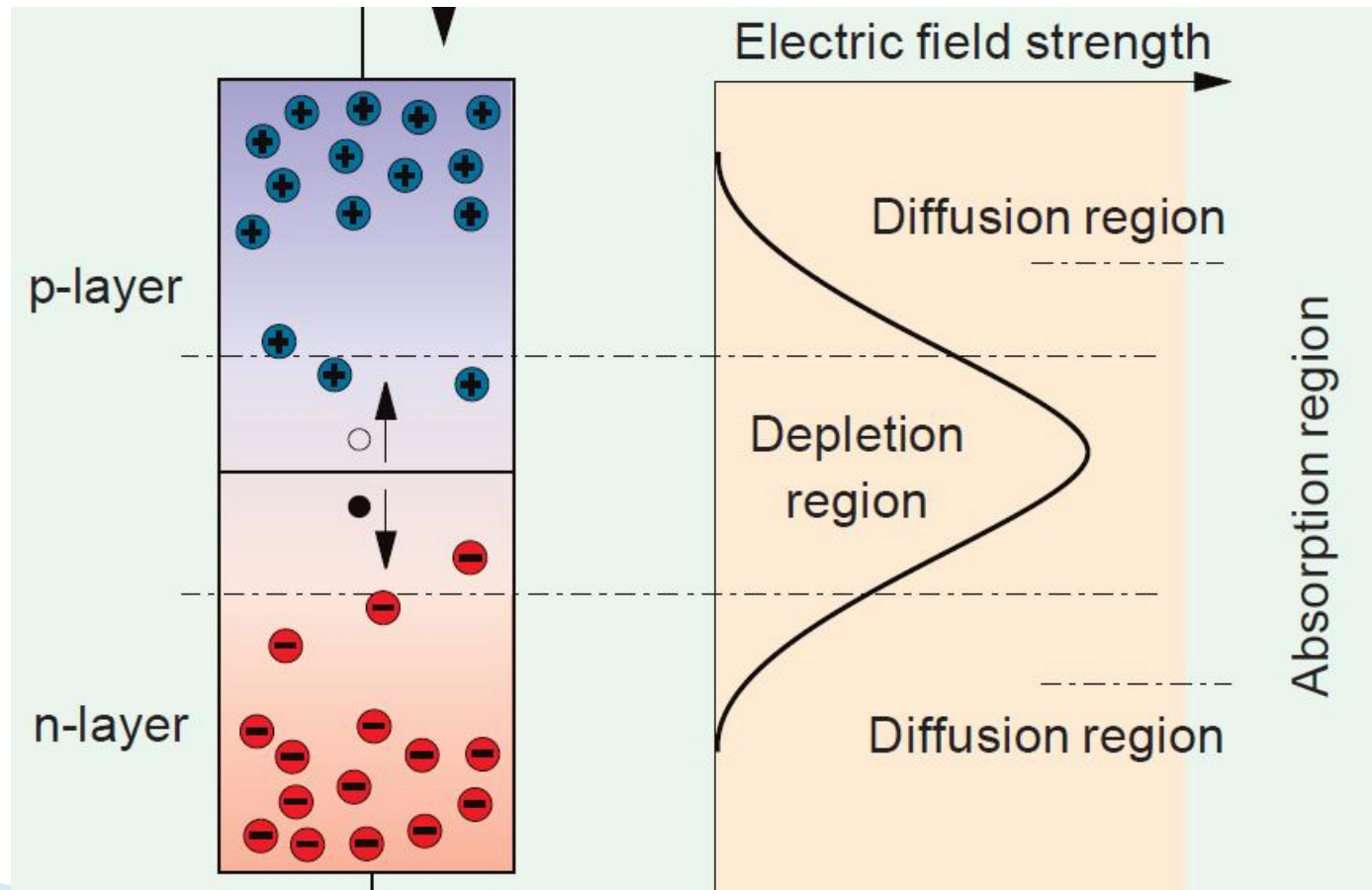
Efect fotovoltaic

▶ joncțiunea pn



Efect fotovoltaic

- ▶ joncțiunea pn / Fotodioda

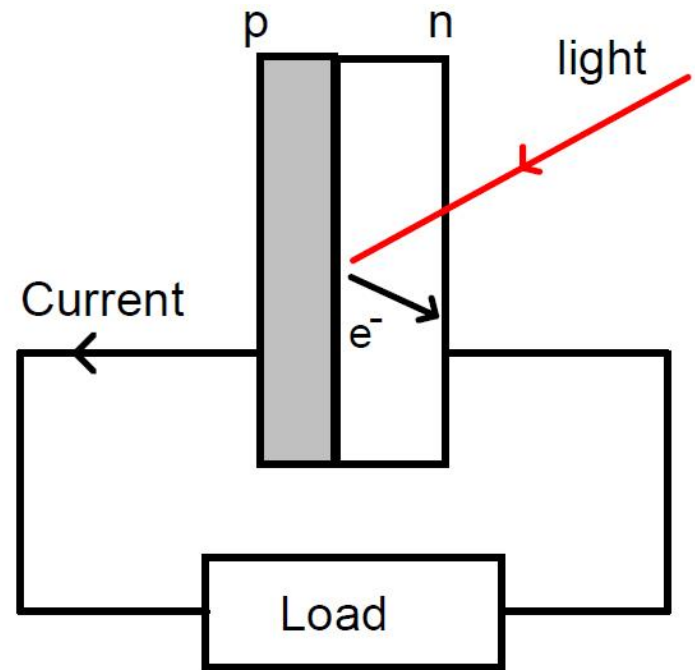
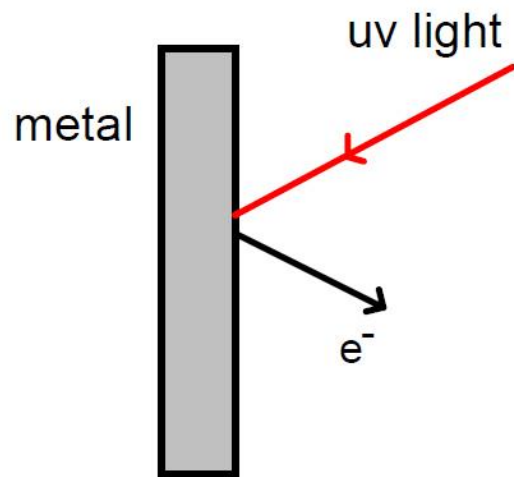


Efect fotovoltaic

- ▶ 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)

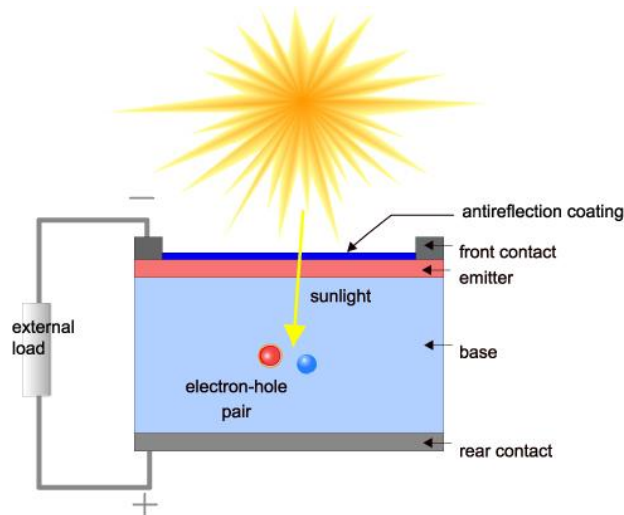


Efect fotovoltaic

- ▶ Separarea fizica a sarcinilor este de obicei realizata prin utilizarea unei jonctiuni pn:
 - campul electric generat de distributia 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)

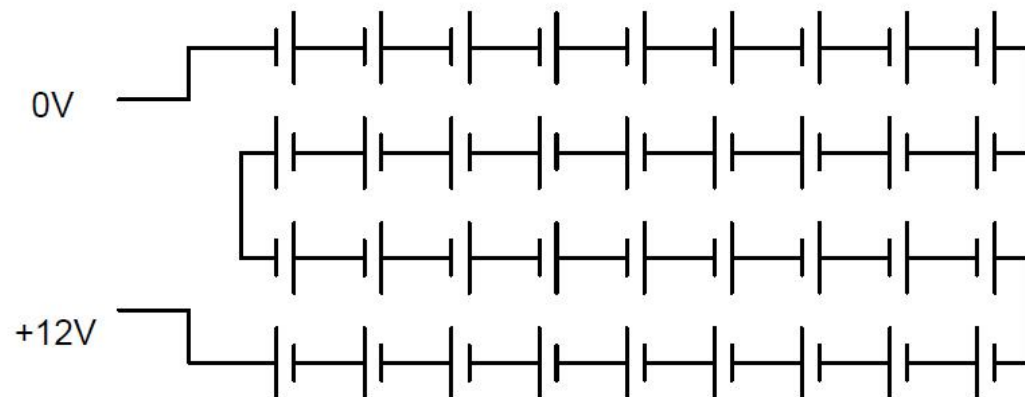
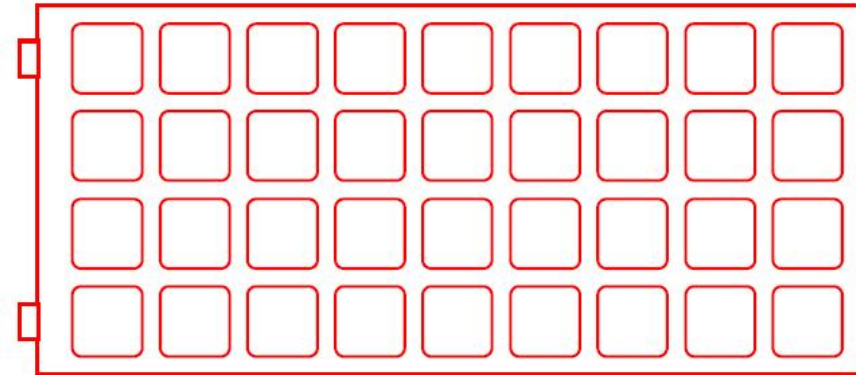
Celula solara (fotovoltaica)

- ▶ in principiu o dioda
 - cu arie mare ($\sim 100\text{cm}^2$)
 - cu suprafata tratata antireflectorizant
 - genereaza o tensiune electromotoare de $0.5\div 1\text{V}$
 - genereaza curenti de scurtcircuit de $x0\text{ mA/cm}^2$



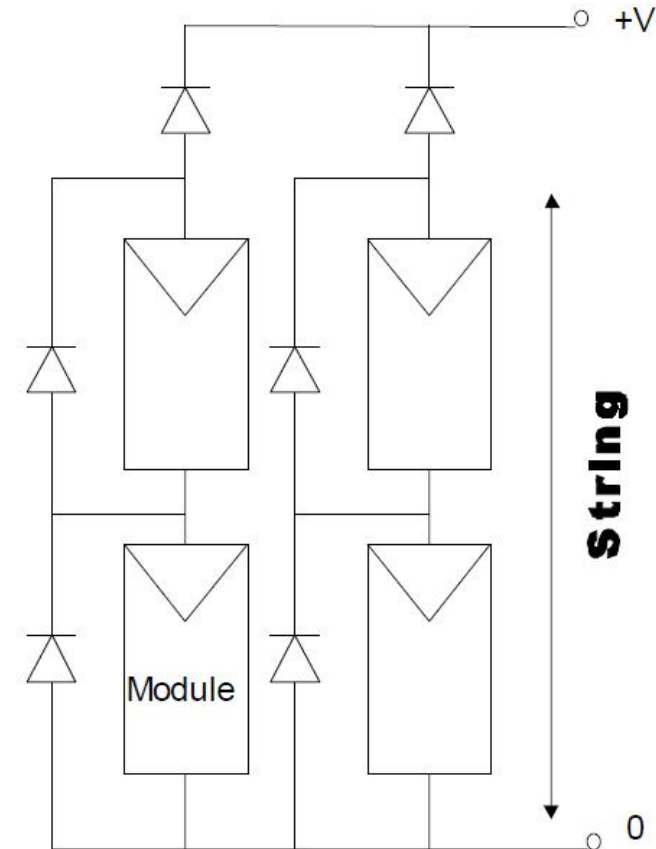
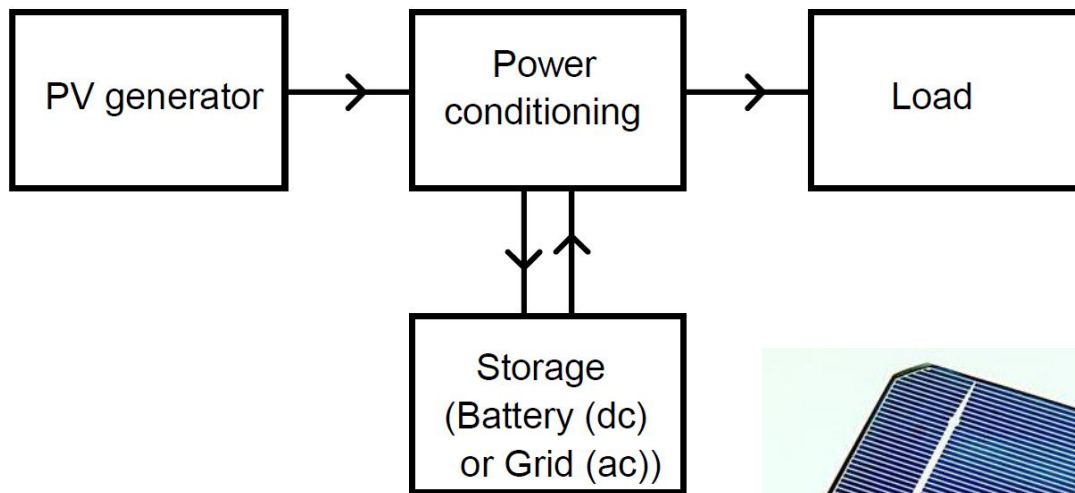
Celula solara (fotovoltaica)

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



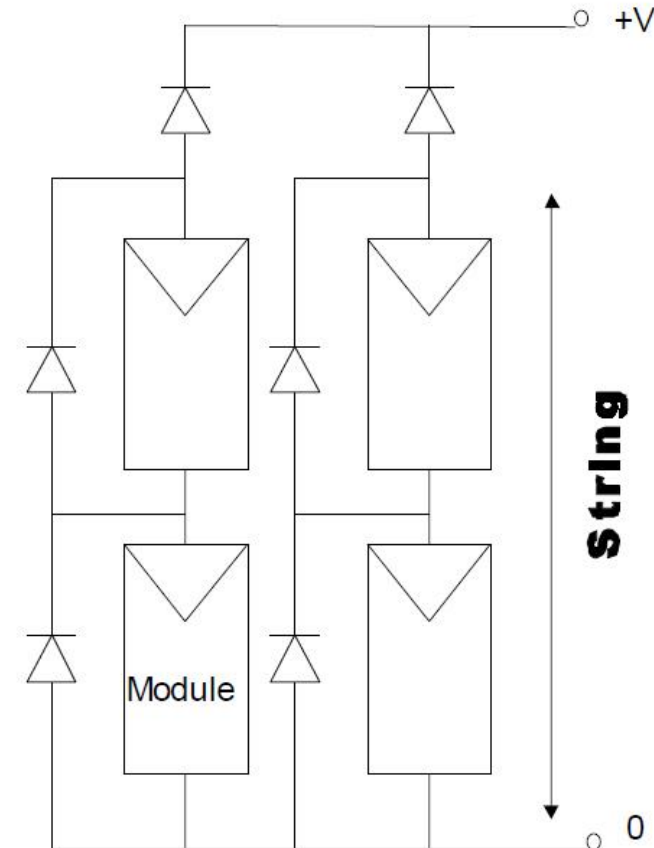
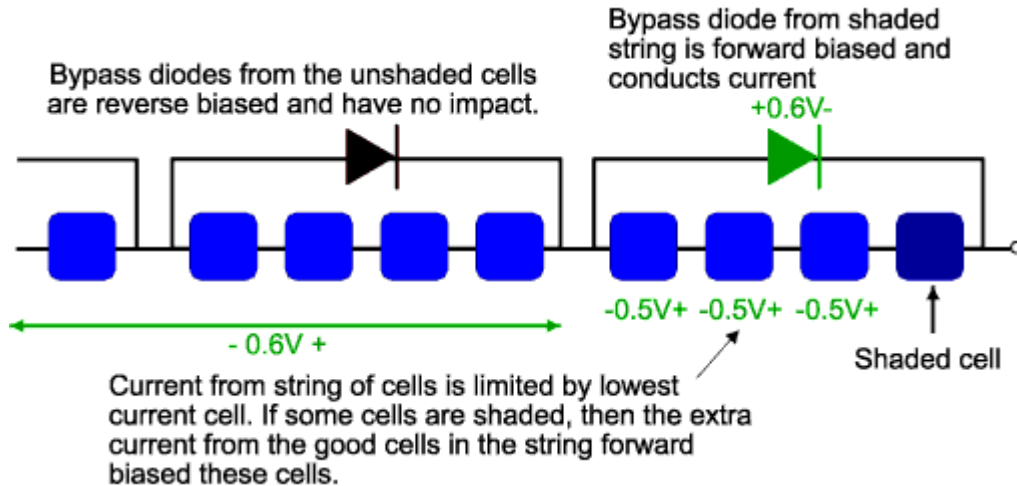
Celula solara (fotovoltaica)

- ▶ 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)

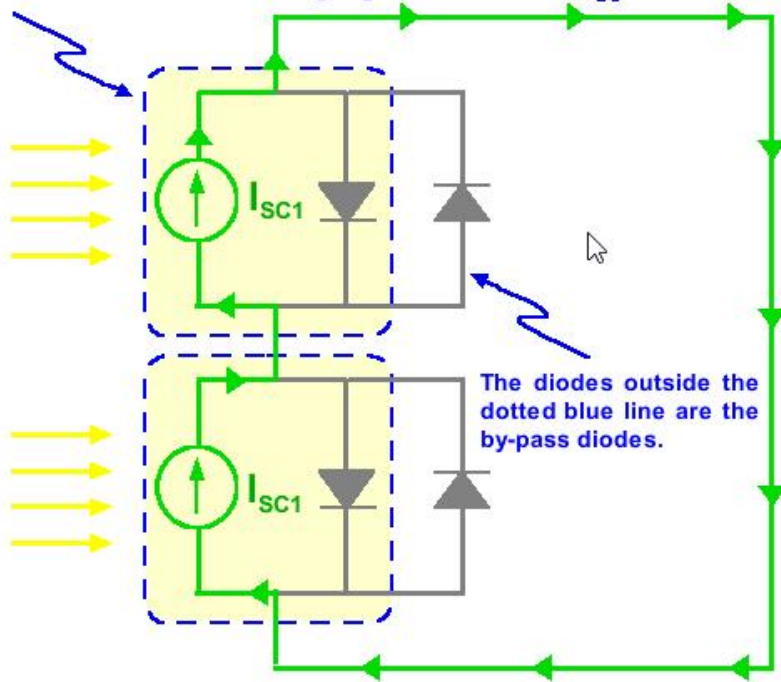
▶ Diode bypass

SERIES CONNECTED SOLAR CELLS WITH BYPASS DIODES

- Matched currents at short circuit
- Mismatched currents at short circuit
- Matched currents at open circuit
- Mismatched currents at open circuit

At short circuit conditions and with matched currents, the voltage across both the solar cells and the bypass diodes is zero. The bypass diodes have no effect.

The circuit elements contained within the blue dotted lines model a solar cell. The current source is the light generated current, I_{sc} .

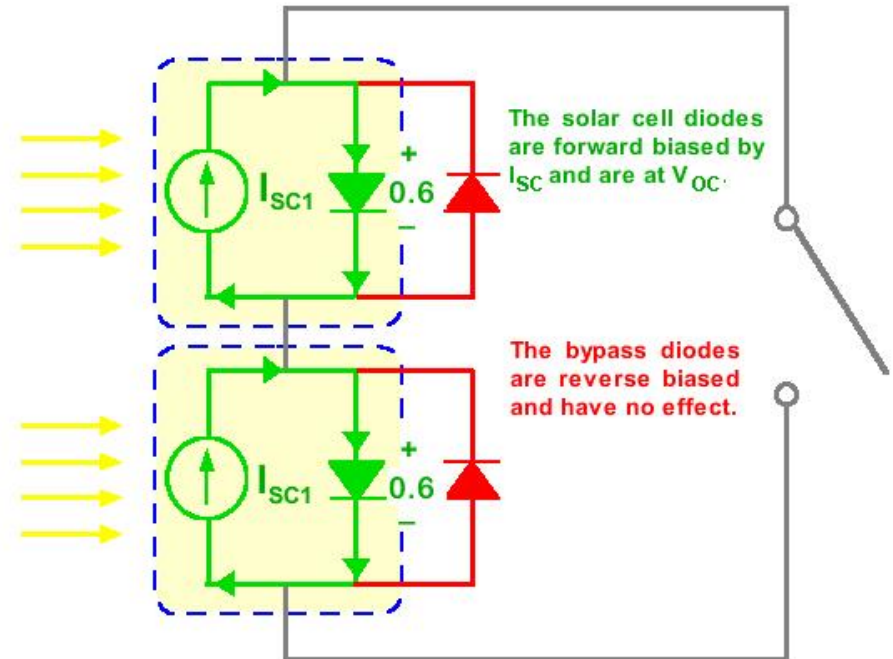


The diodes outside the dotted blue line are the by-pass diodes.

SERIES CONNECTED SOLAR CELLS WITH BYPASS DIODES

- Matched currents at short circuit
- Mismatched currents at short circuit
- Matched currents at open circuit
- Mismatched currents at open circuit

At open circuit conditions and with matched currents, the short circuit current from each solar cell forward biases the solar cell. The bypass diodes are reverse biased and have no effect on the circuit.



The solar cell diodes are forward biased by I_{sc} and are at V_{oc} .

The bypass diodes are reverse biased and have no effect.

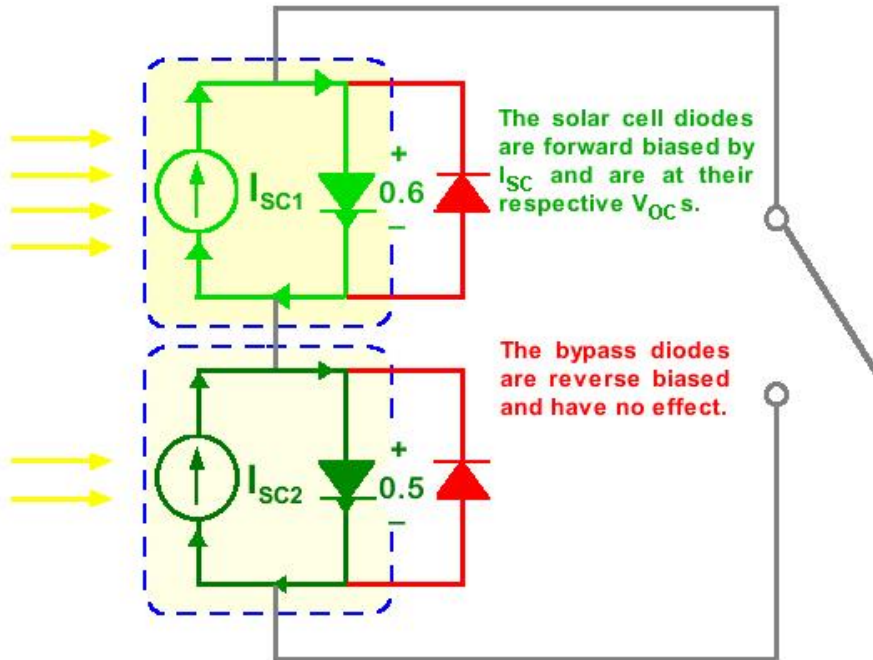
Celula solara (fotovoltaica)

▶ Diode bypass

SERIES CONNECTED SOLAR CELLS WITH BYPASS DIODES

- Matched currents at short circuit
- Mismatched currents at short circuit
- Matched currents at open circuit
- Mismatched currents at open circuit

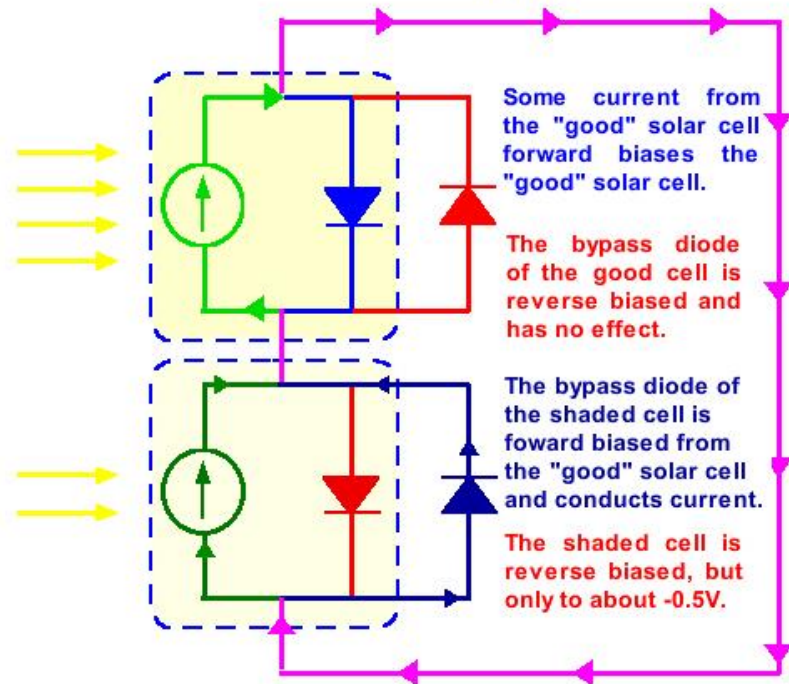
At open circuit conditions and with mismatched currents, the shaded solar cell has a reduced V_{OC} . The by-pass diodes are reverse biased and have no effect.



SERIES CONNECTED SOLAR CELLS WITH BYPASS DIODES

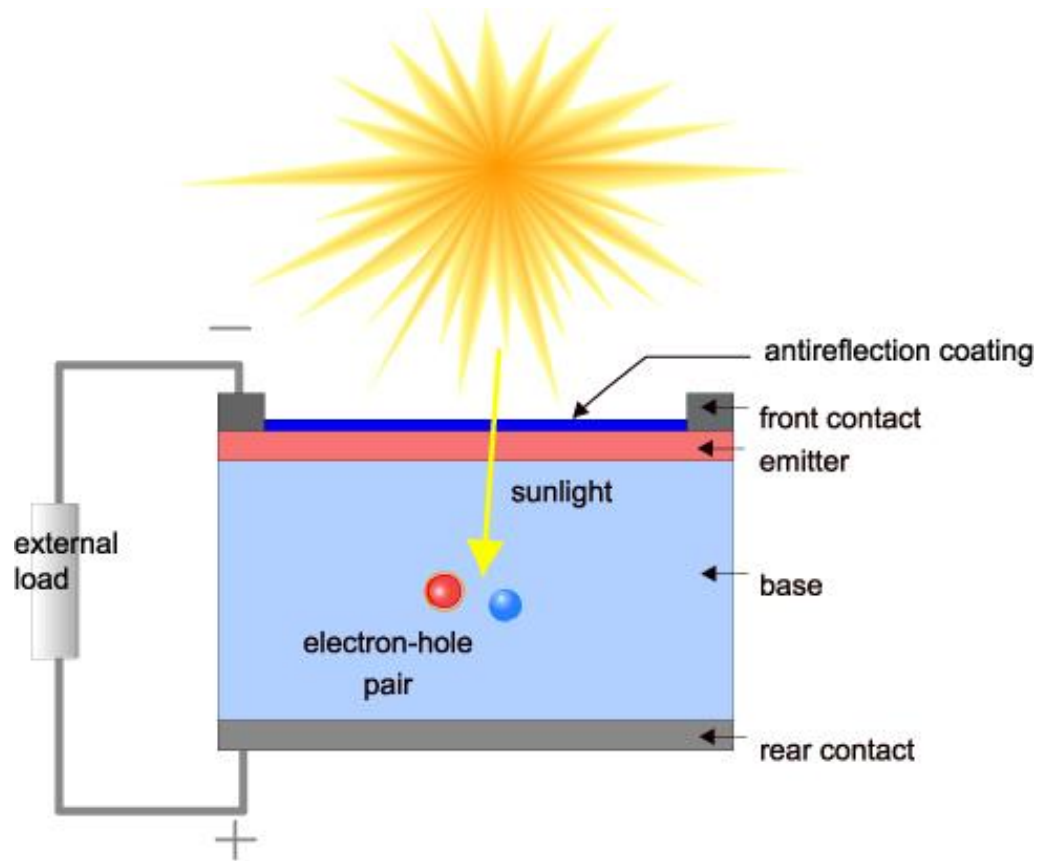
- Matched currents at short circuit
- Mismatched currents at short circuit
- Matched currents at open circuit
- Mismatched currents at open circuit

At short circuit with mismatched I_{SC} some current flows across the "good" solar cell junction, forward biasing the "good" solar cell. This voltage in turn forward biases the by-pass diode of the shaded cell, allowing it to conduct current.



Celula solara (fotovoltaica)

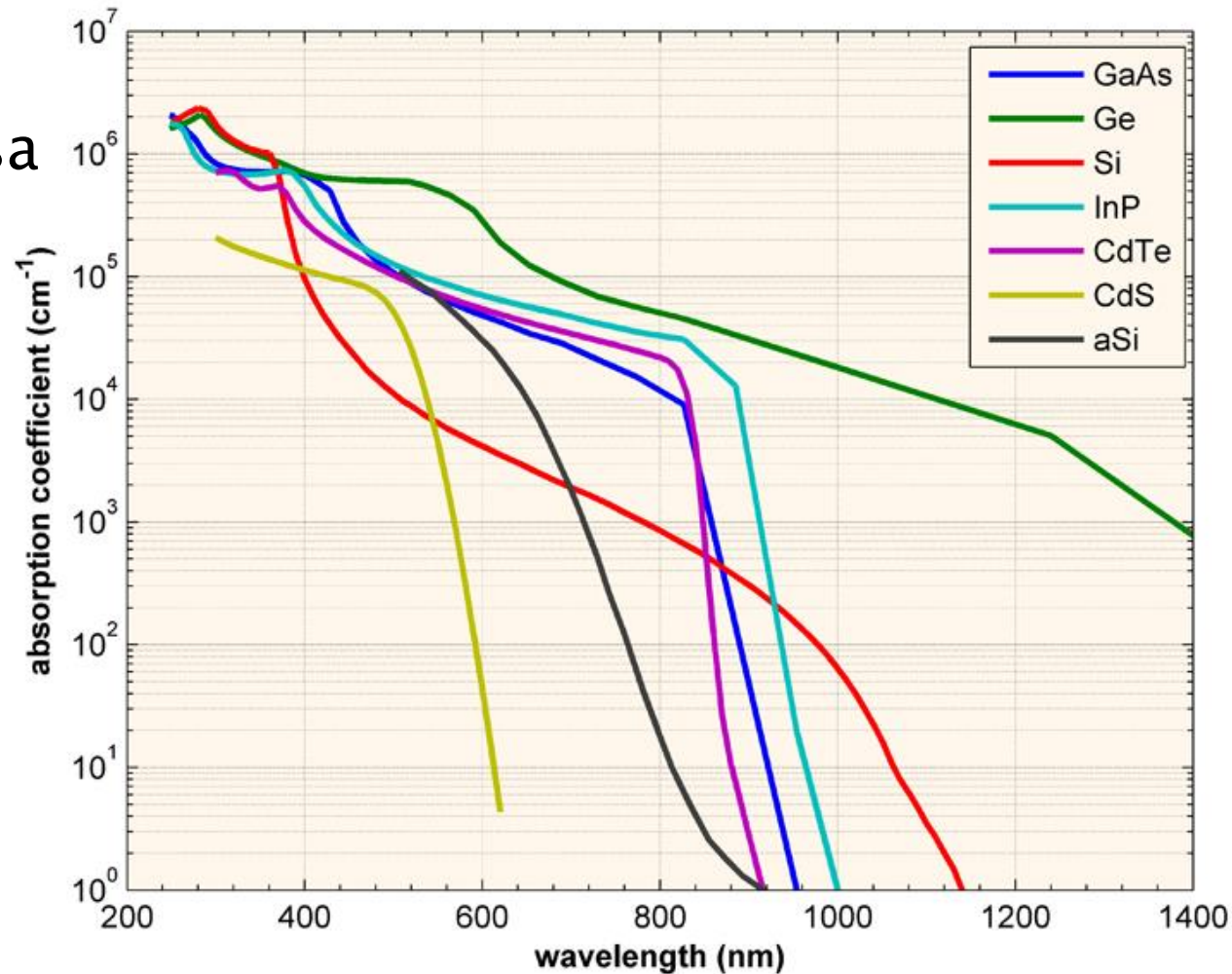
- ▶ in principiu o dioda



Celula solara

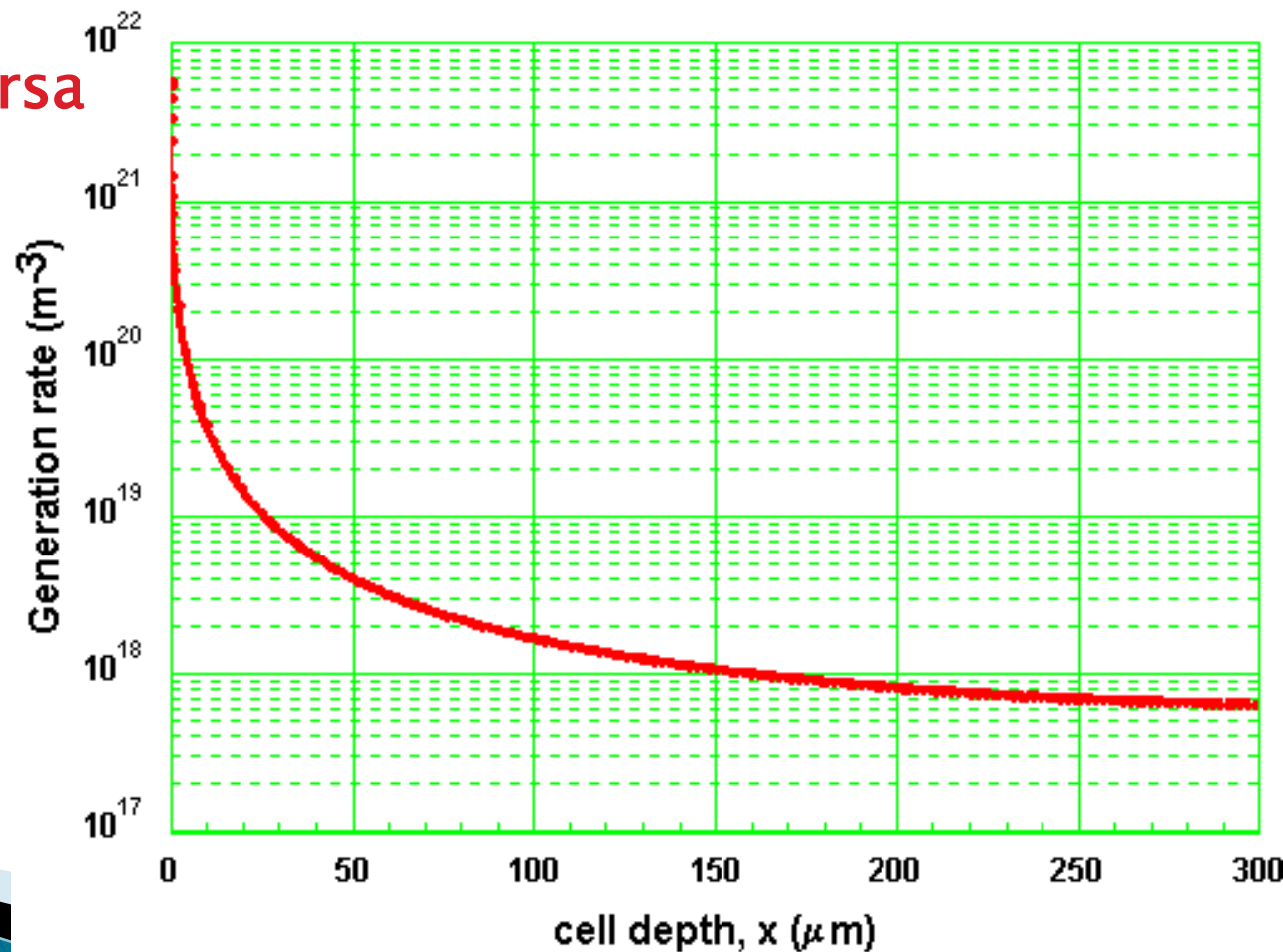
► probabilitate de generare a purtatorilor depinde de

- **material**
- distanta parcursa



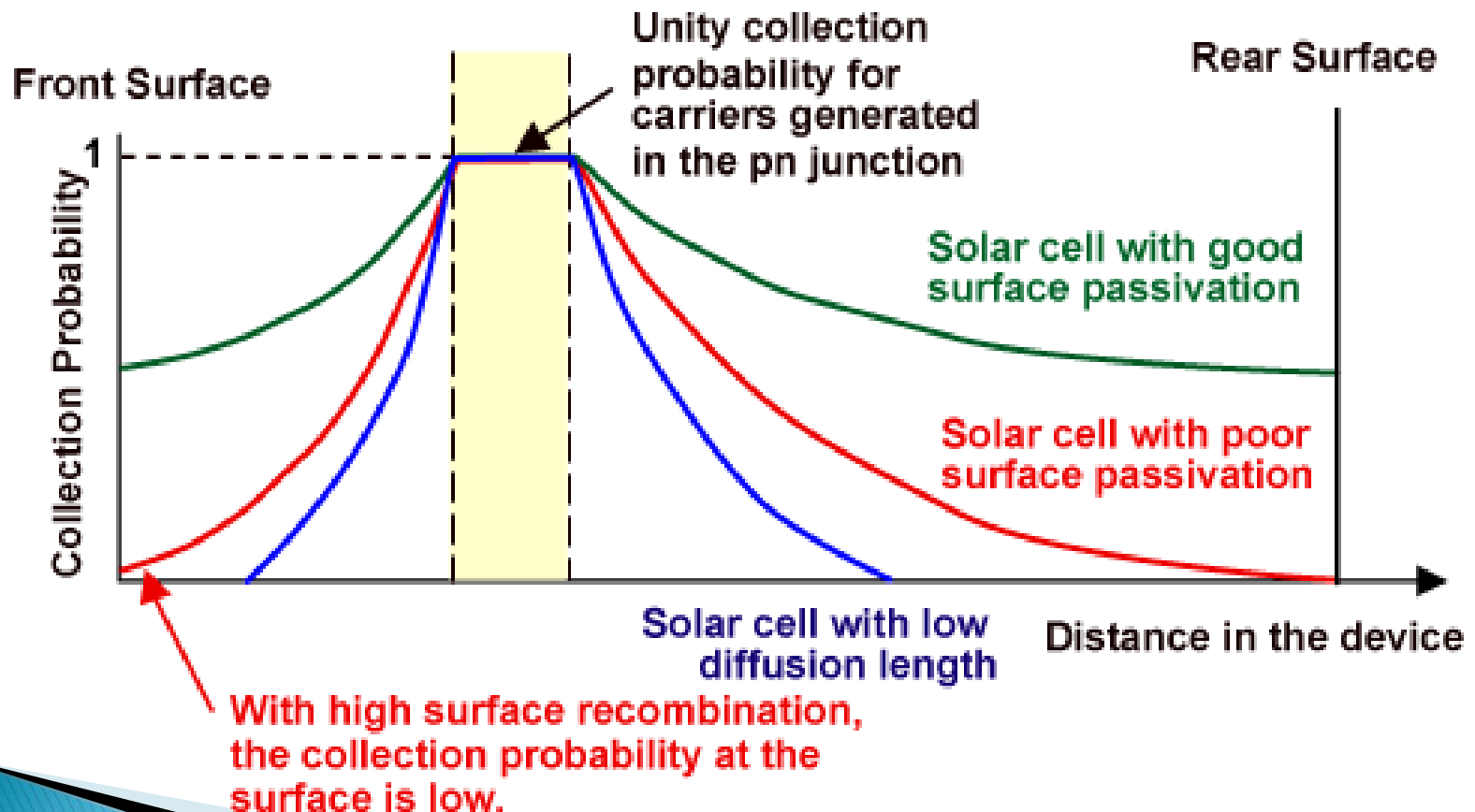
Celula solara

- ▶ probabilitate de generare a purtatorilor depinde de
 - material
 - **distanța parcursă**



Celula solara

- ▶ probabilitate de captura a purtatorilor



Celula solara/Fotodioda

- ▶ Energia necesara pentru eliberarea unei perechi electron gol

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

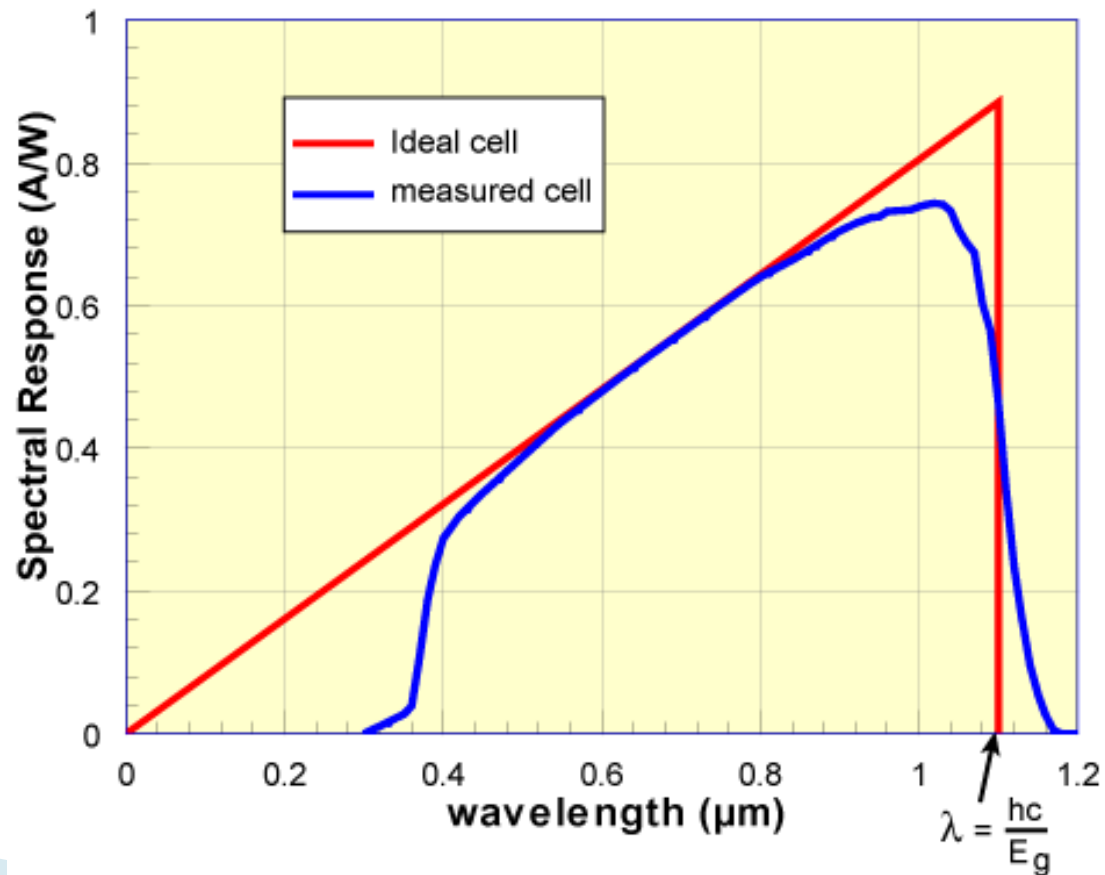
- ▶ Lungime de unda de taiere

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

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

Celula solara

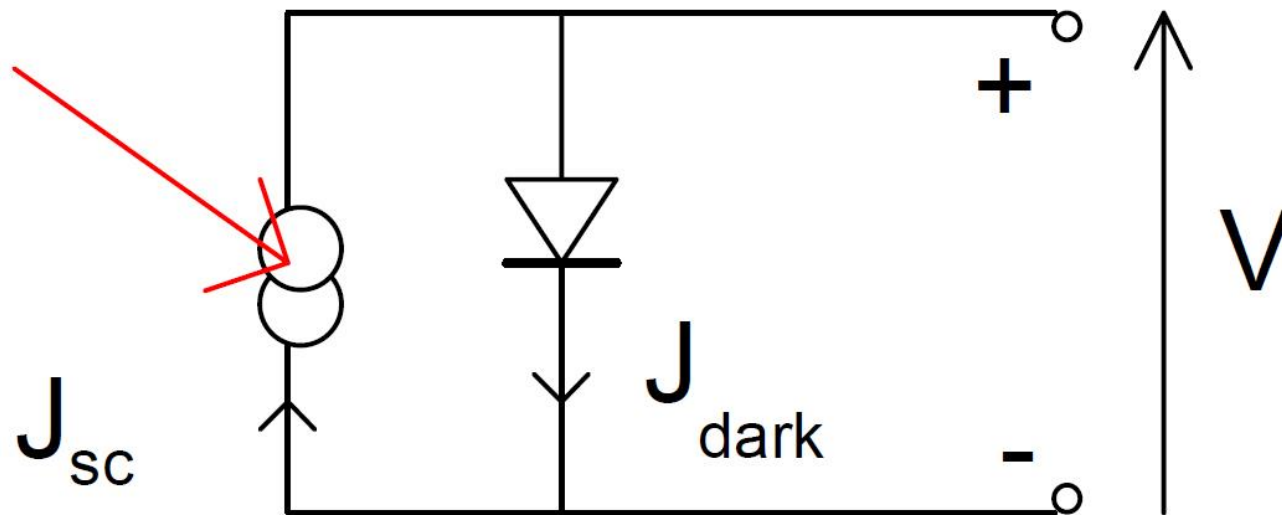
- ▶ raspuns spectral



Celula solara

- ▶ Schema echivalenta

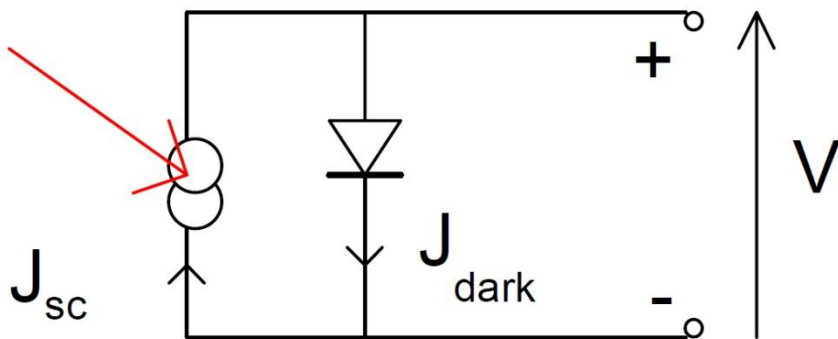
- dioda
- sursa de curent generat de fluxul de fotoni incident



Celula solara

▶ Schema echivalenta

- dioda
- sursa de curent generat de iluminarea energetica incidenta



- curent de intuneric

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

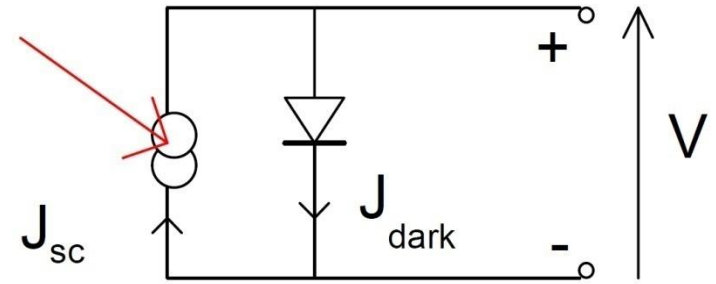
- adaugarea curentului generat de fotoni

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

- tensiunea in gol

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

Celula solara



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

J_{sc}

Light current

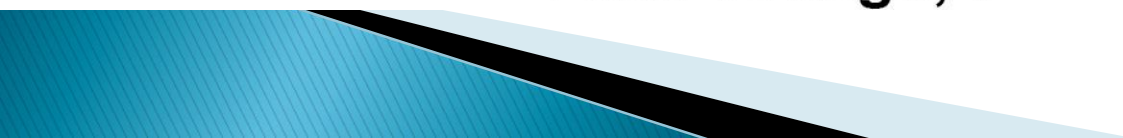
Dark current

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

V_{oc}

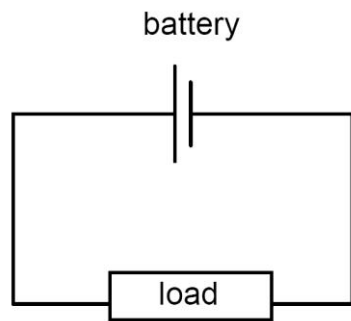
Bias voltage, V

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

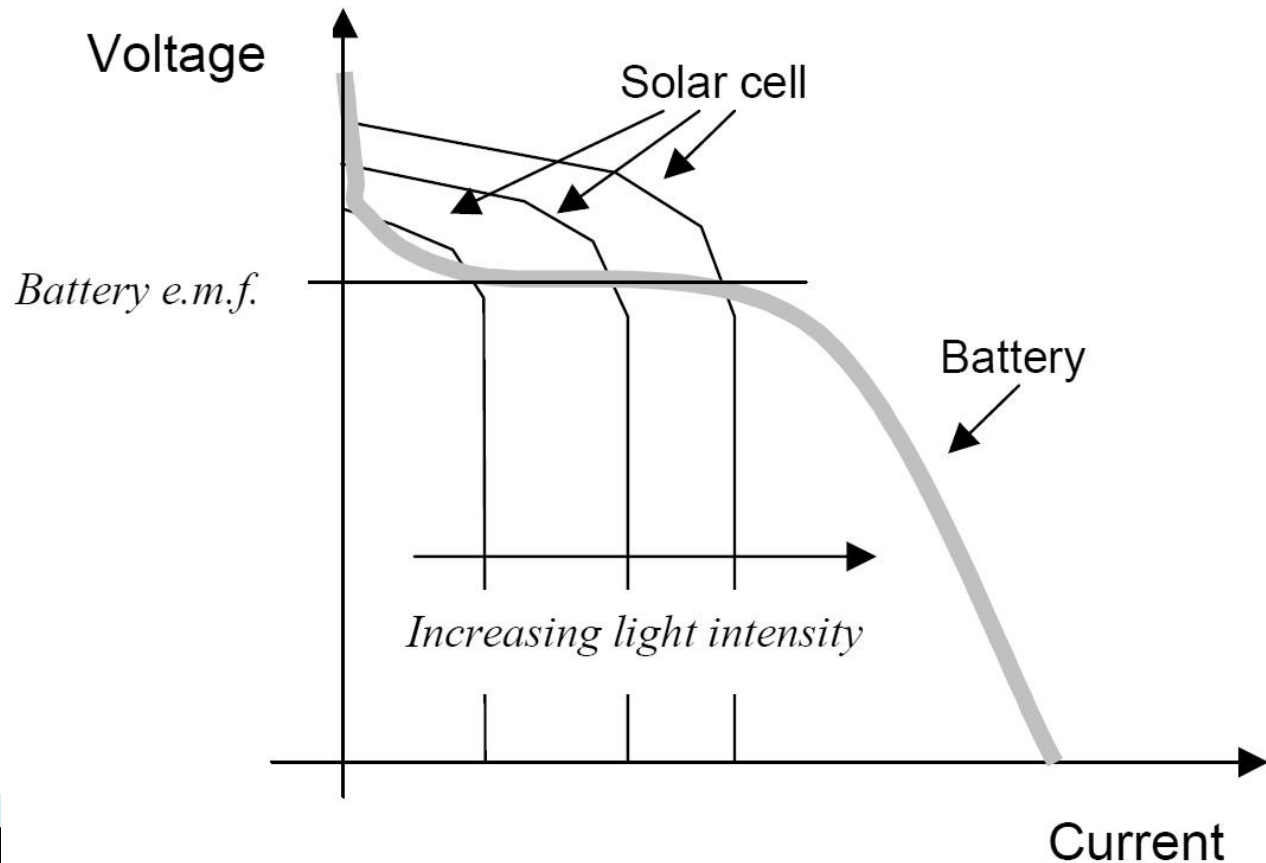
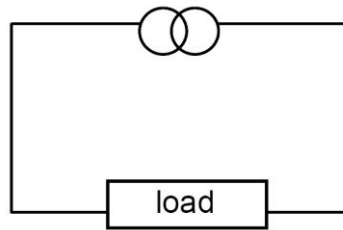


Celula solara

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



solar cell

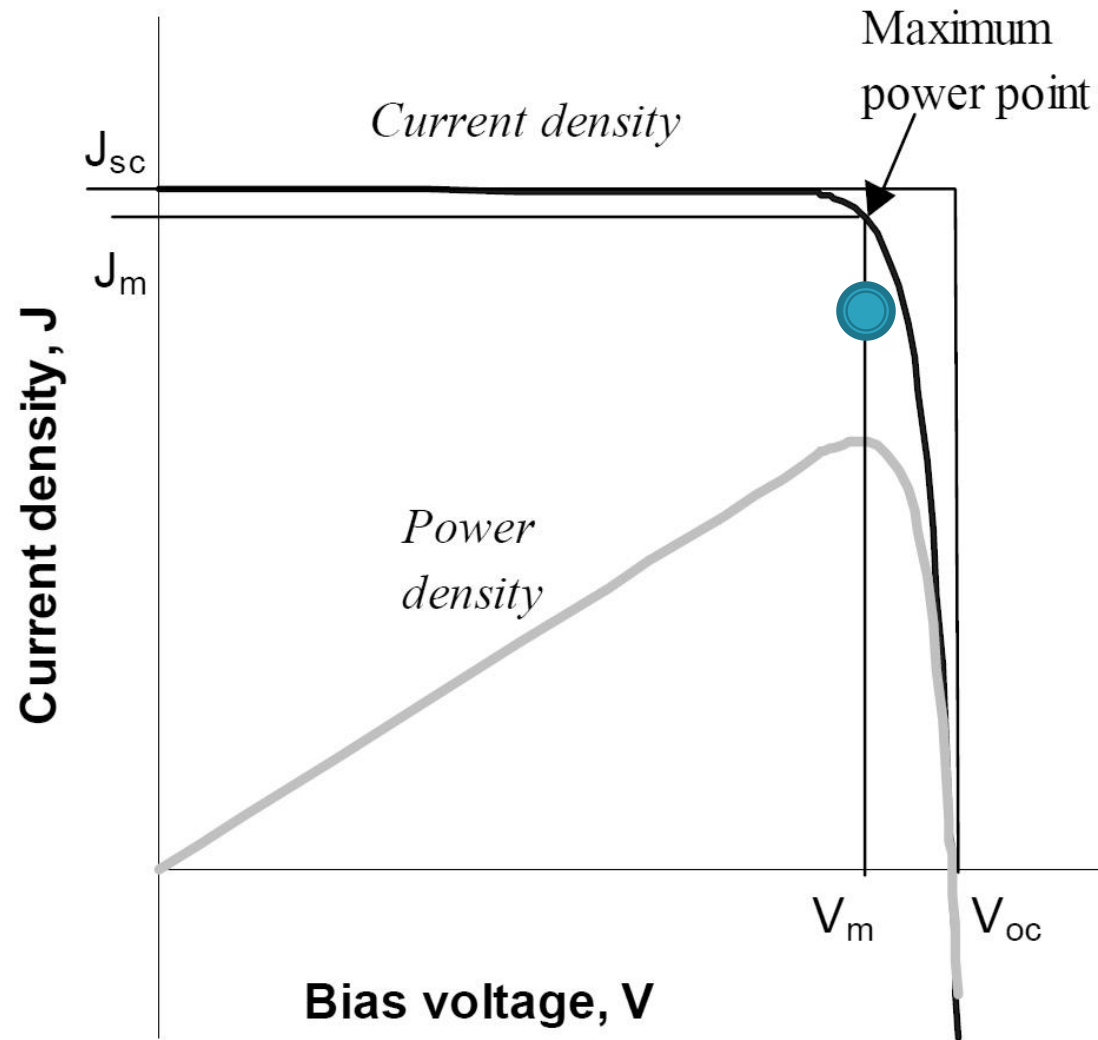
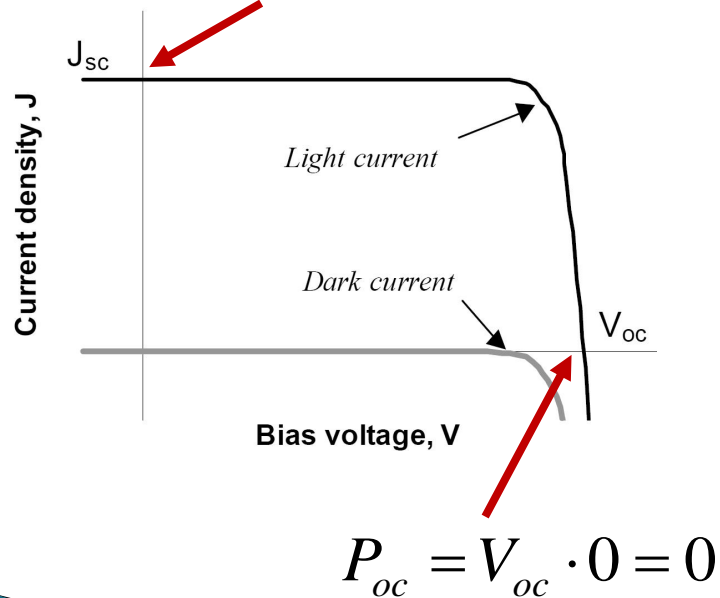


Putere generata

▶ Putere generata

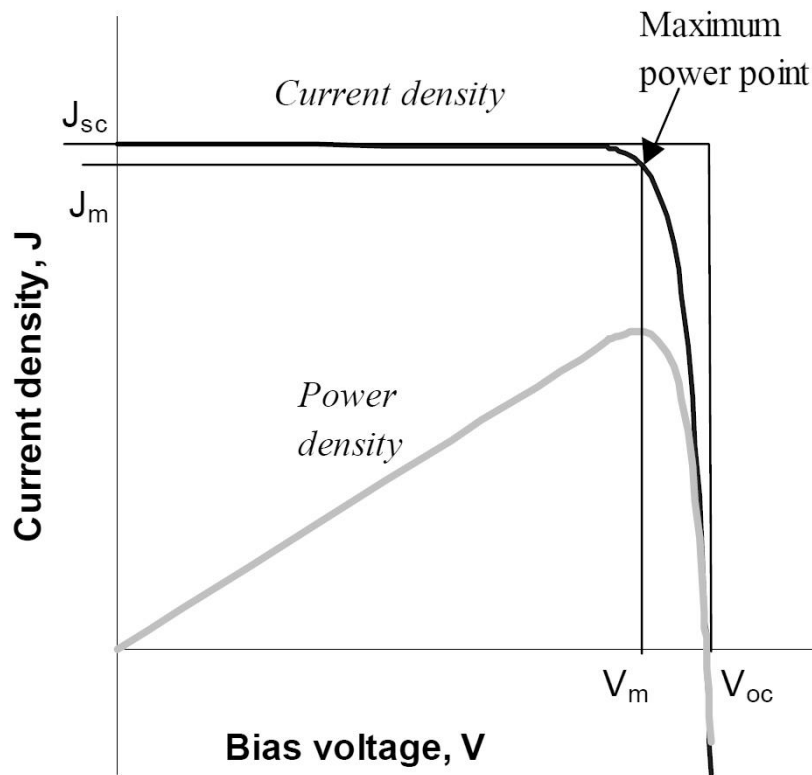
$$P = V \cdot I$$

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



Putere generata

▶ Putere generata

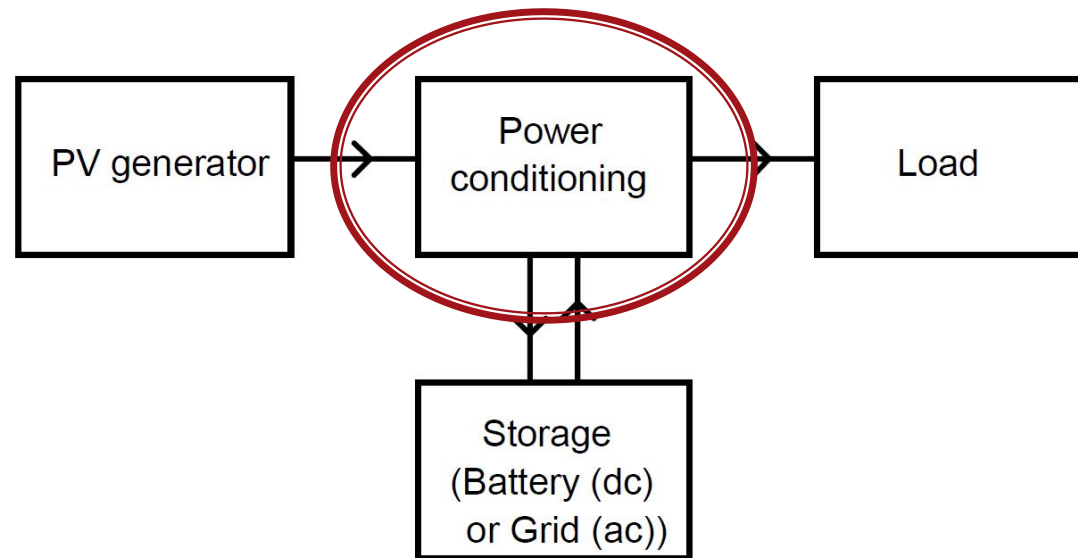


$$P_m = V_{pm} \cdot I_{pm}$$

- ▶ 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 punctului de putere maxima
 - MPPT – Maximum power point tracking



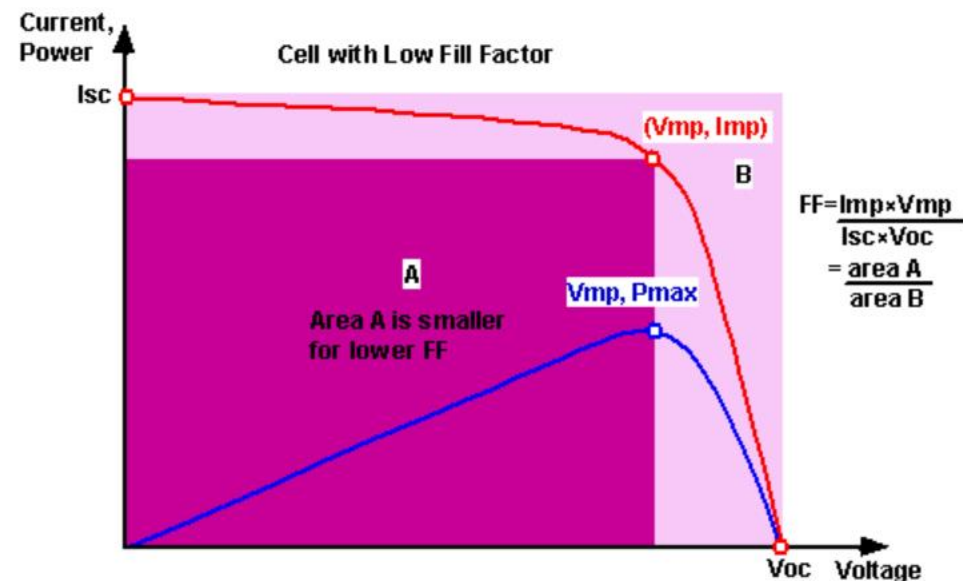
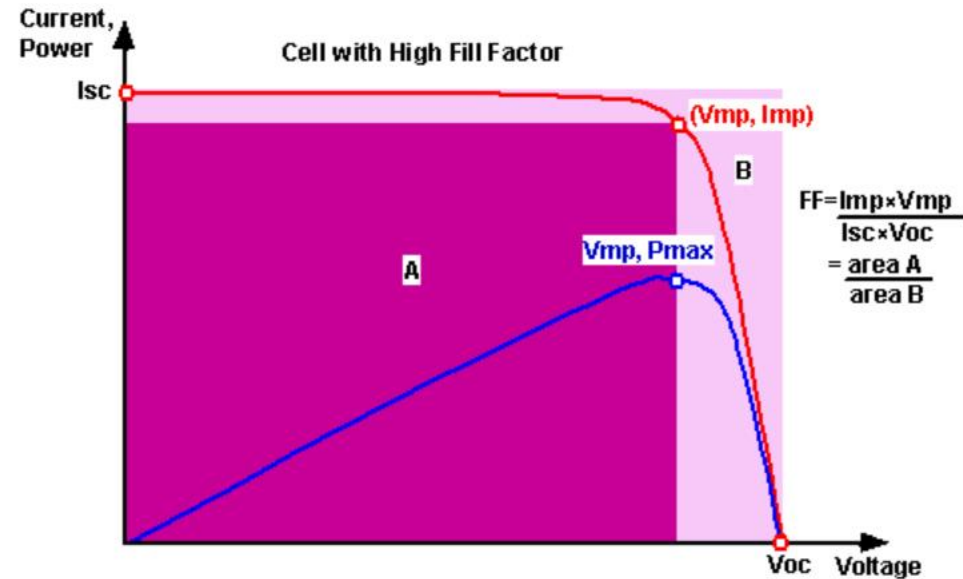
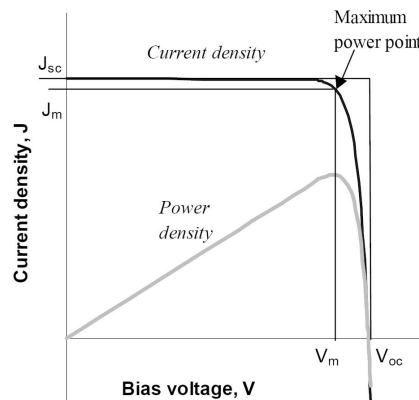
Celula solara

- ▶ Factor de umplere

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

- ▶ o masura a calitatii celulei
 - dependent de material

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



Contact

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