An introduction to solar cells and photo-diodes

Speaker: Giulia Maineri

January 17th, 2022

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A first glance

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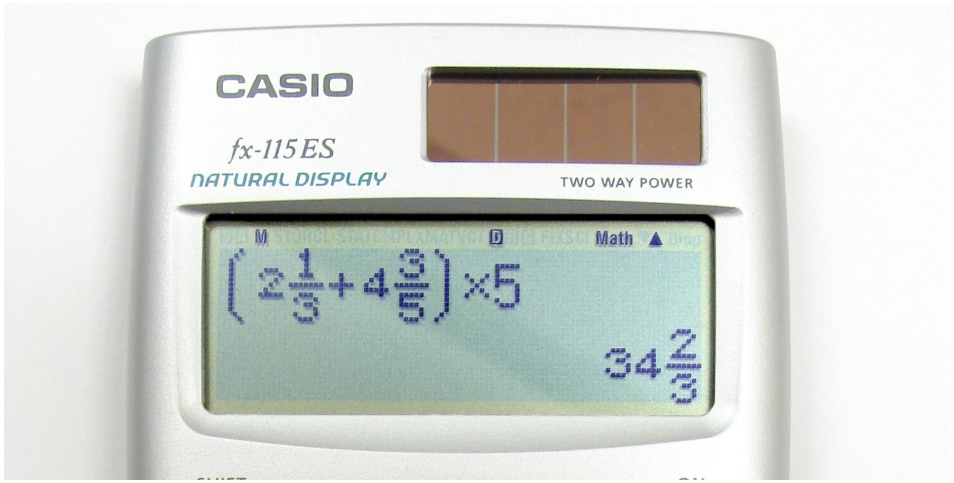

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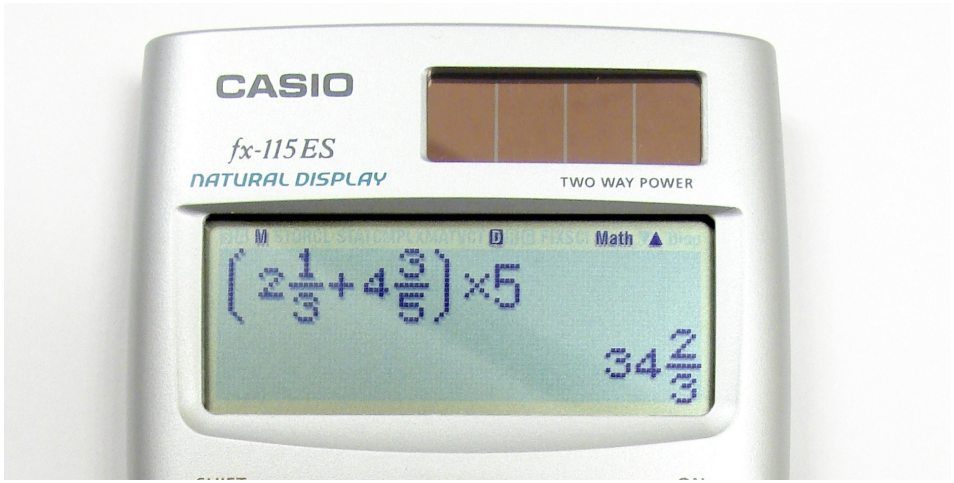

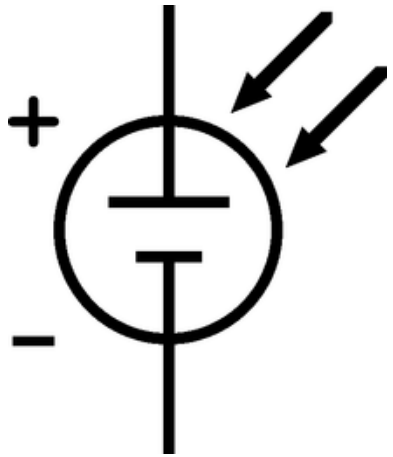

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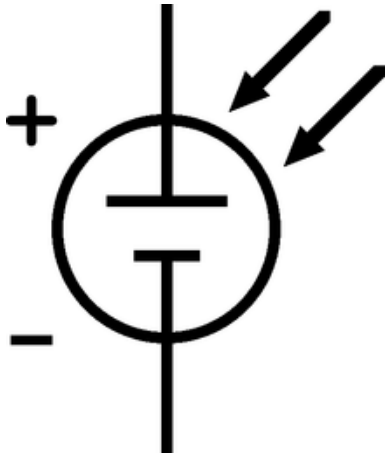

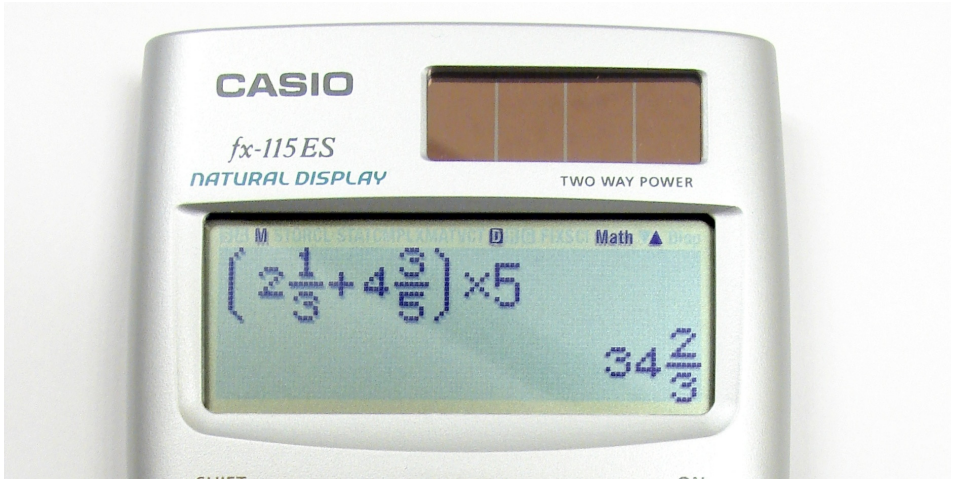

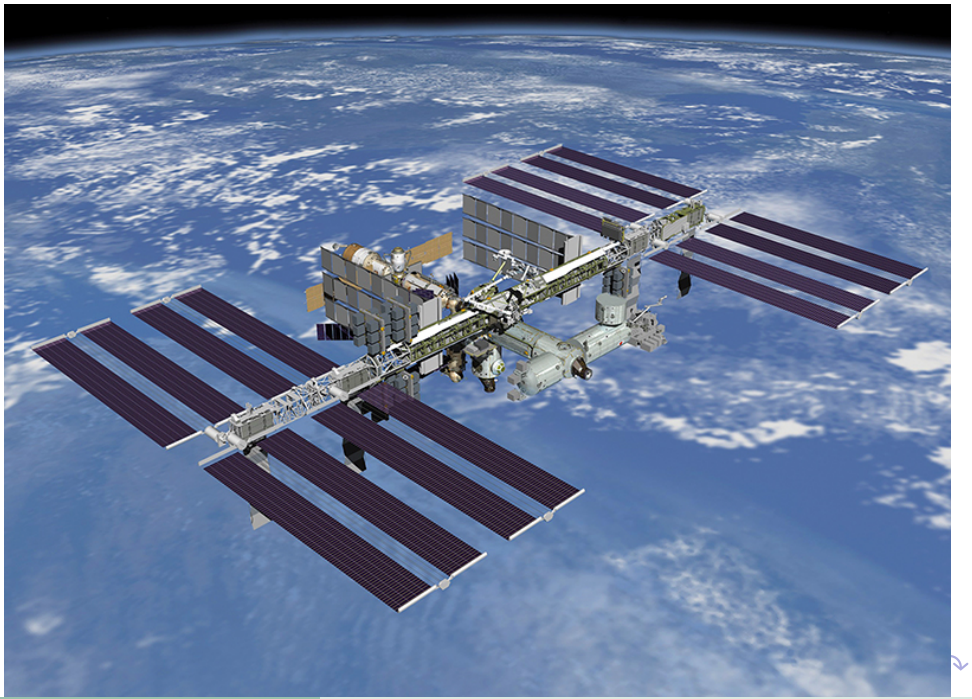

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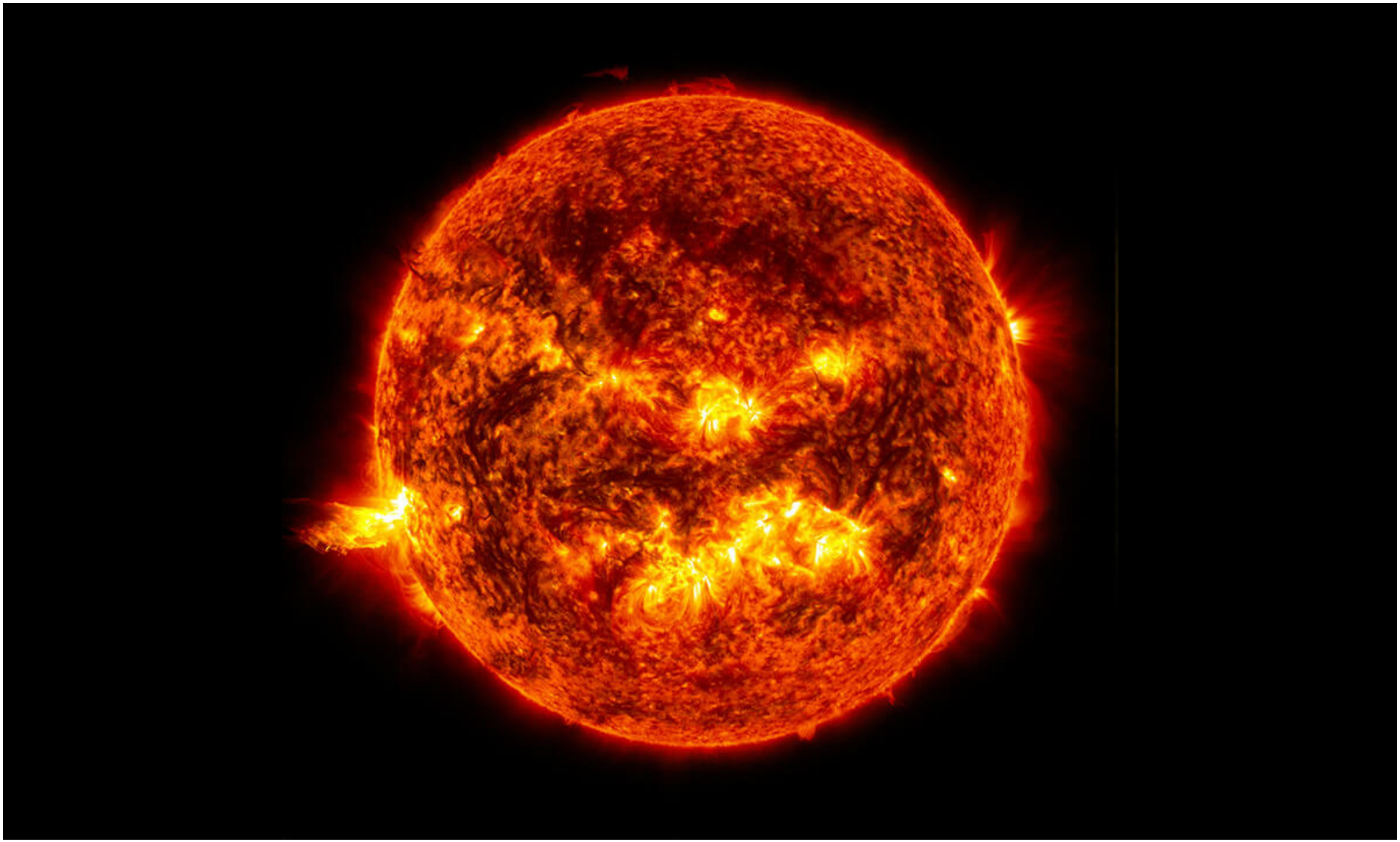

Why solar cells?

Nuclear fusion

$$^1H + ^1H \rightarrow ^2H + e^+ + \nu_e + 3.27 \text{ MeV}$$

$$^2H + ^1H \rightarrow ^3H + \gamma + 4.03 \text{ MeV}$$

$$^3H + ^3H \rightarrow ^4He + 2\,^1H + 17.59 \text{ MeV}$$

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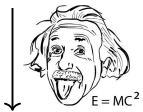

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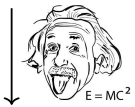

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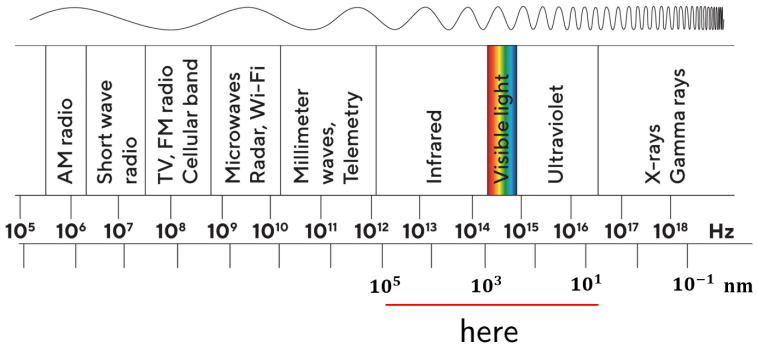

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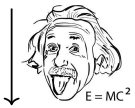

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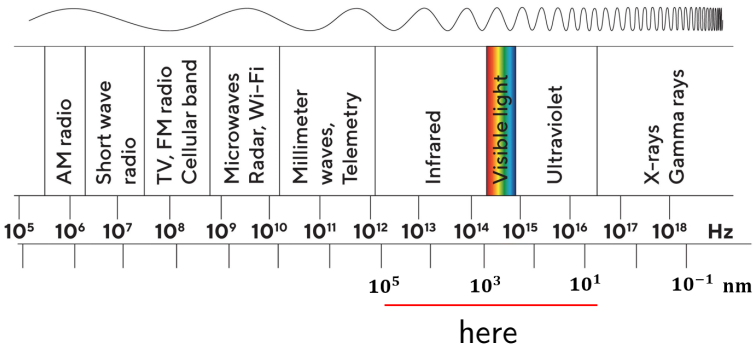

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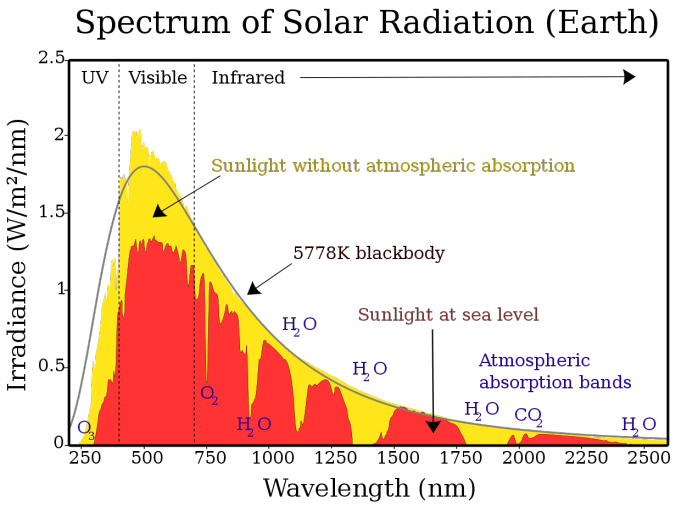

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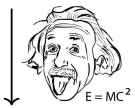

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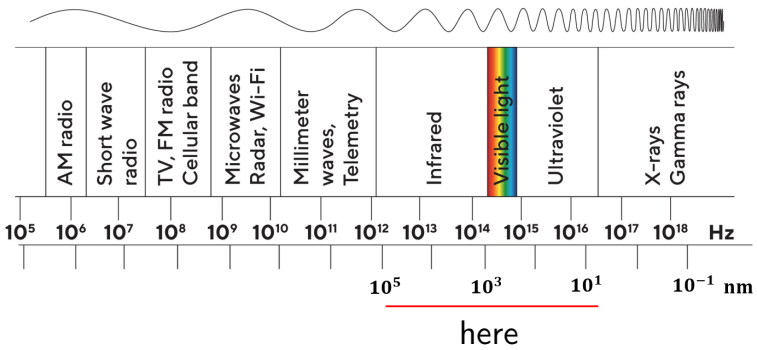

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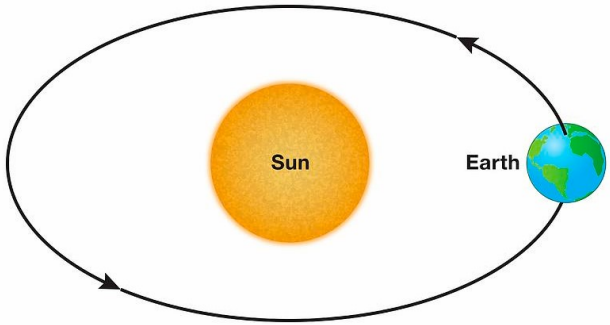
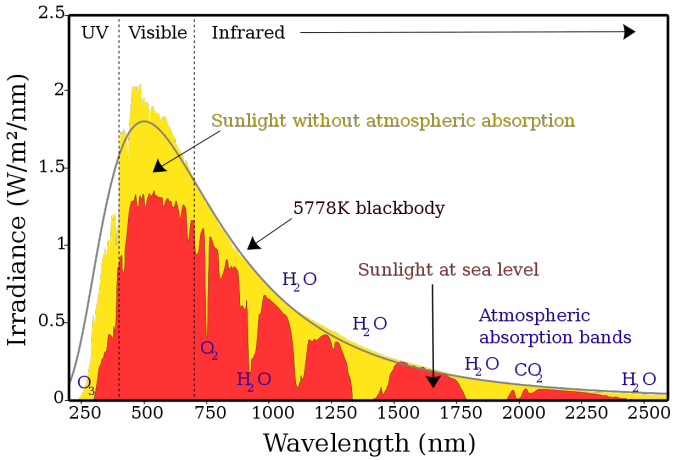
I=1367 W/m^2 → not considering atmosphere attenuation

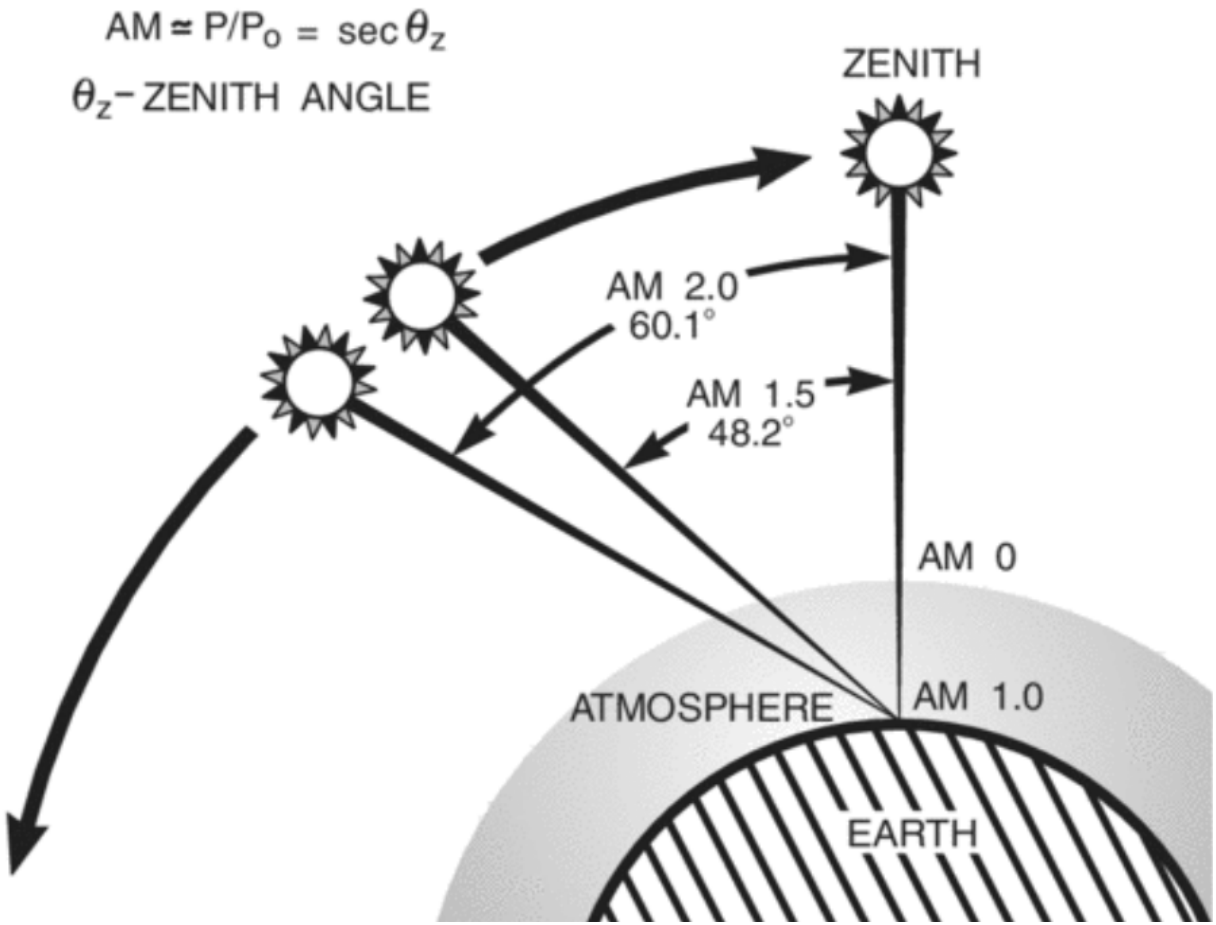


Spectrum of Solar Radiation (Earth)



Why solar cells?

Atmosphere attenuation: Air Mass (AM)



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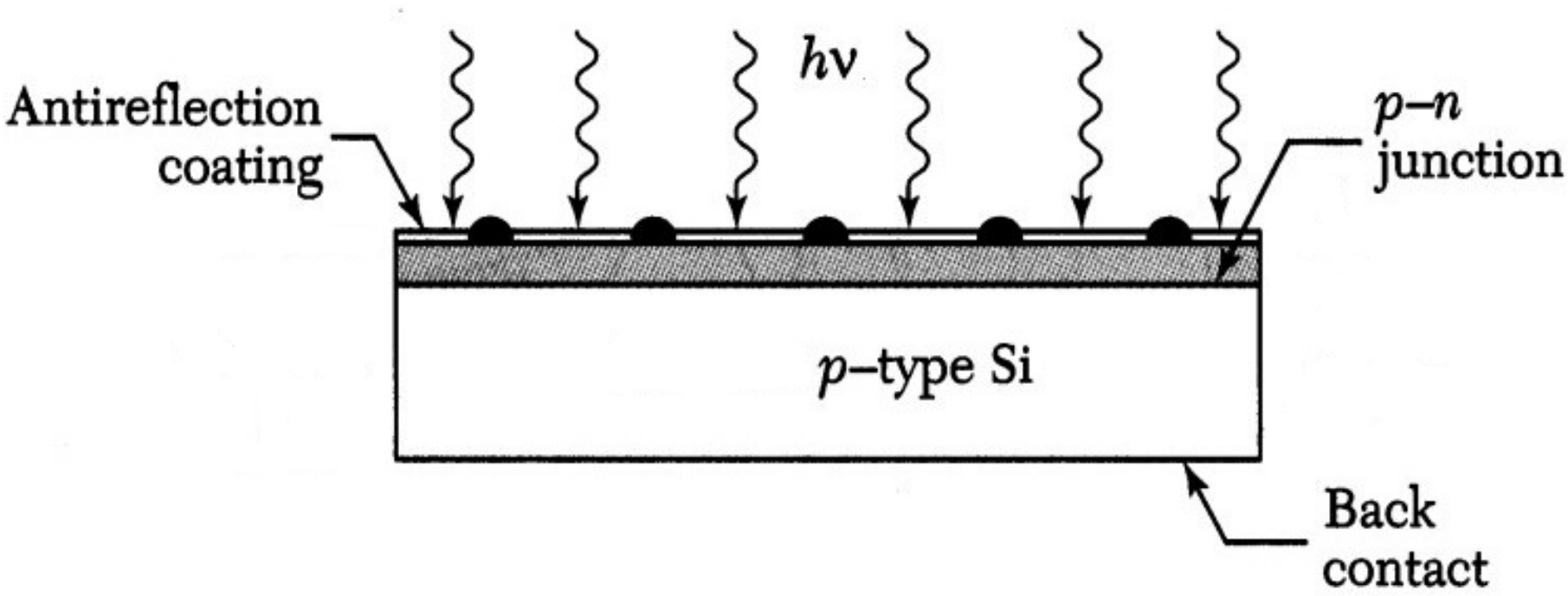

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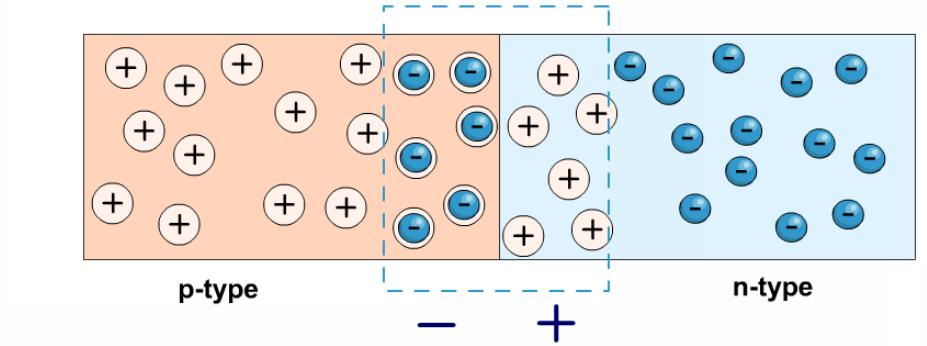

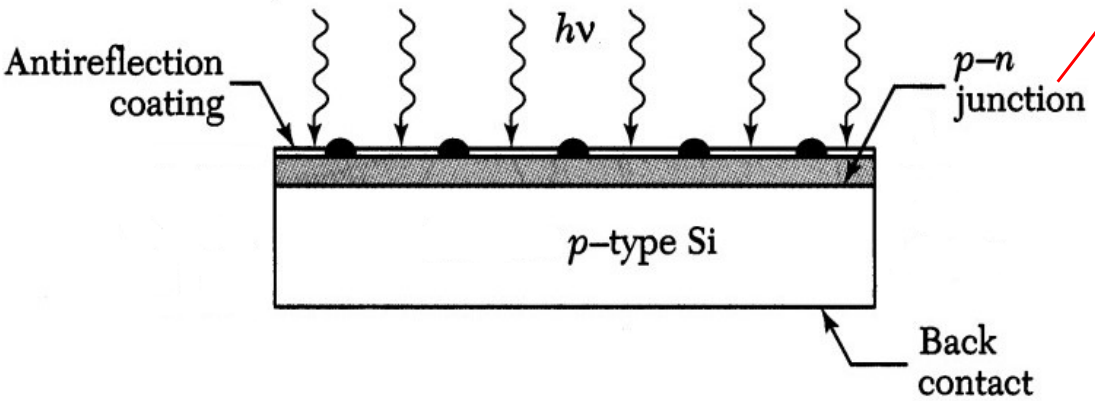

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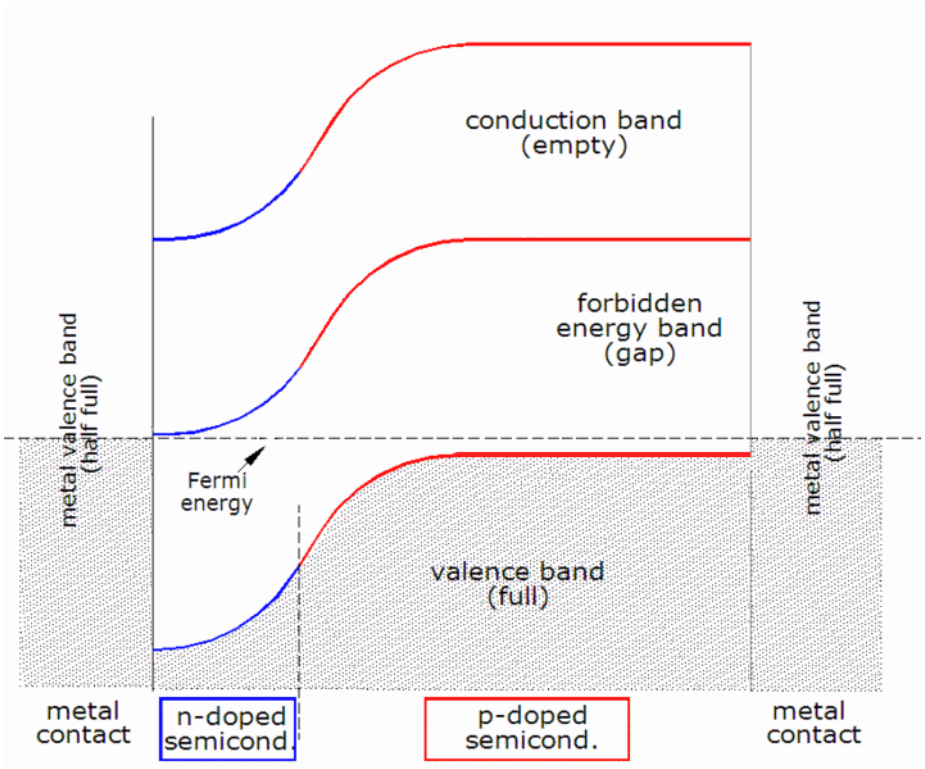

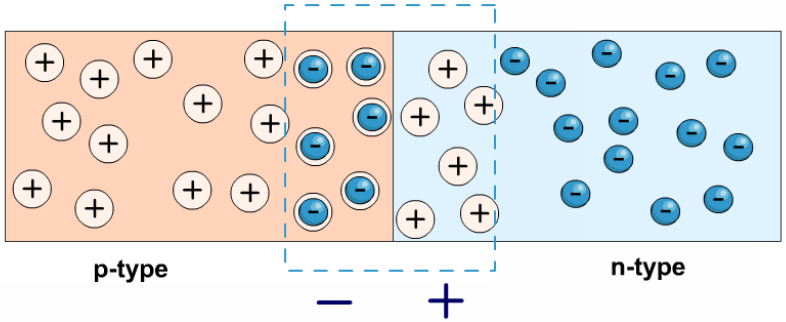

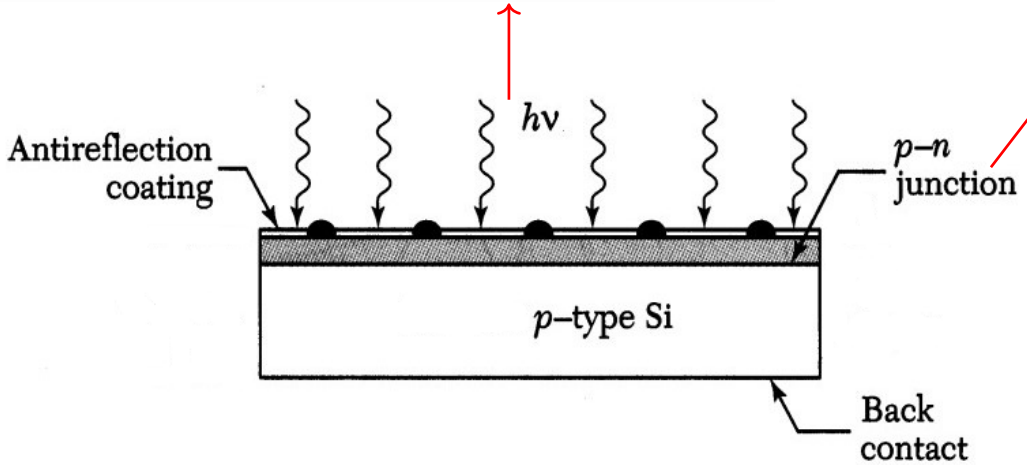

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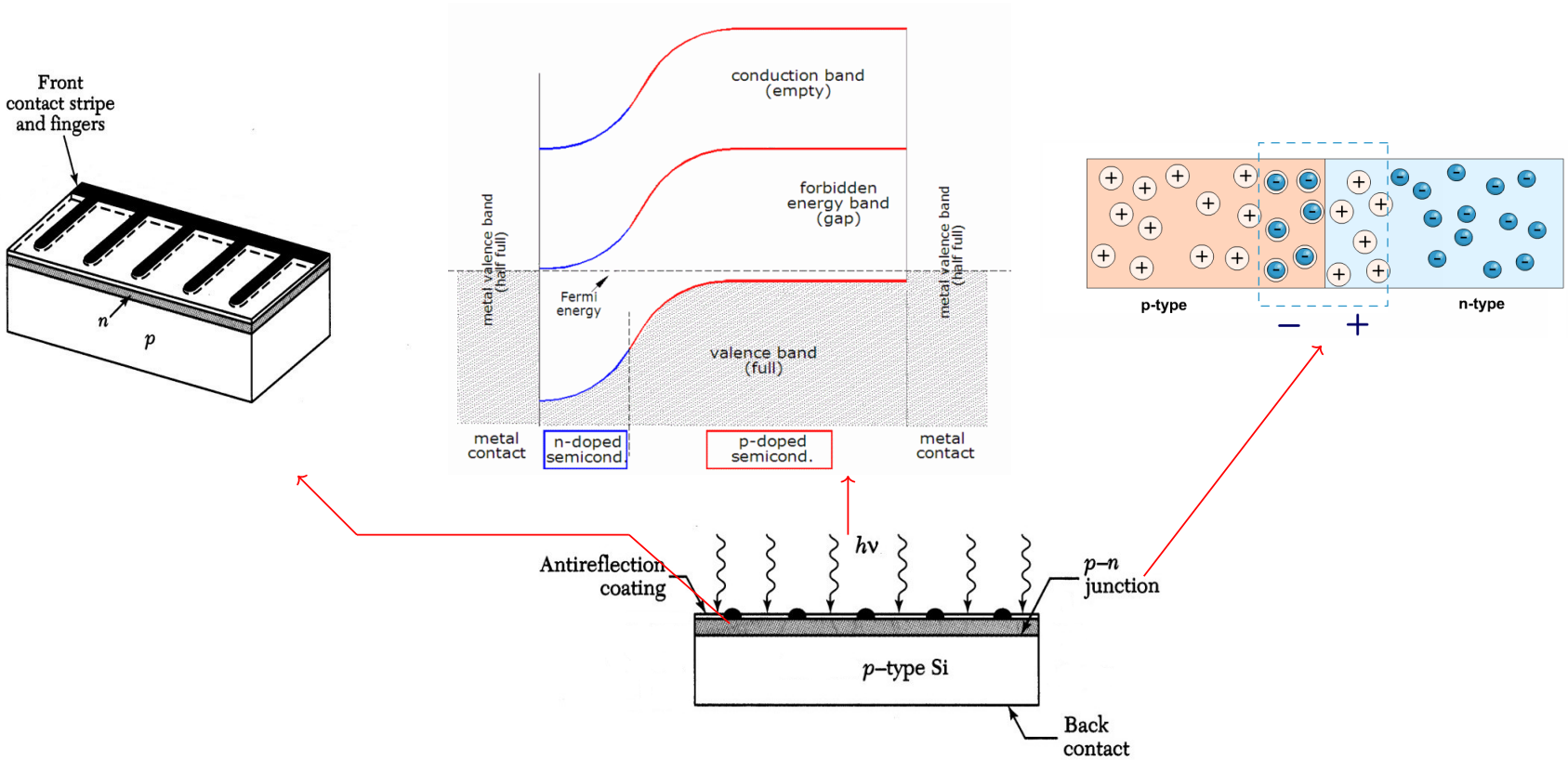

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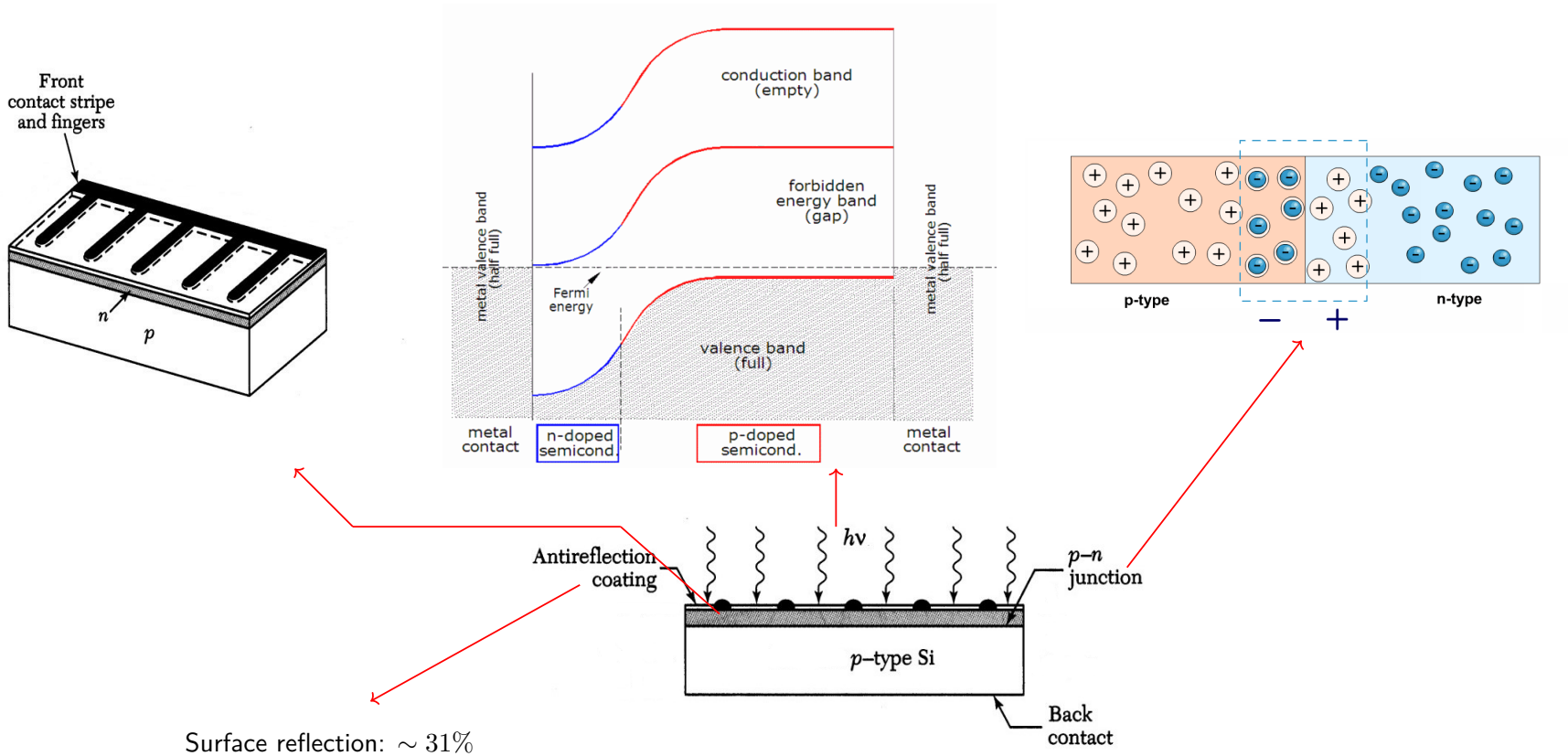

Surface reflection: $\sim 31\%$

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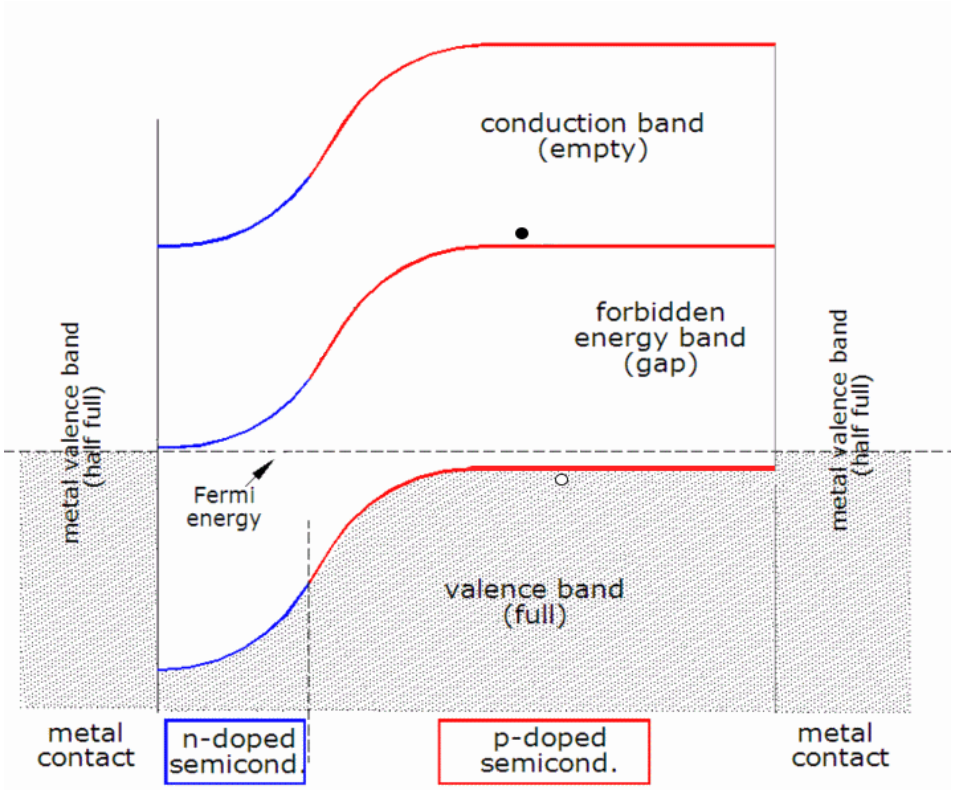

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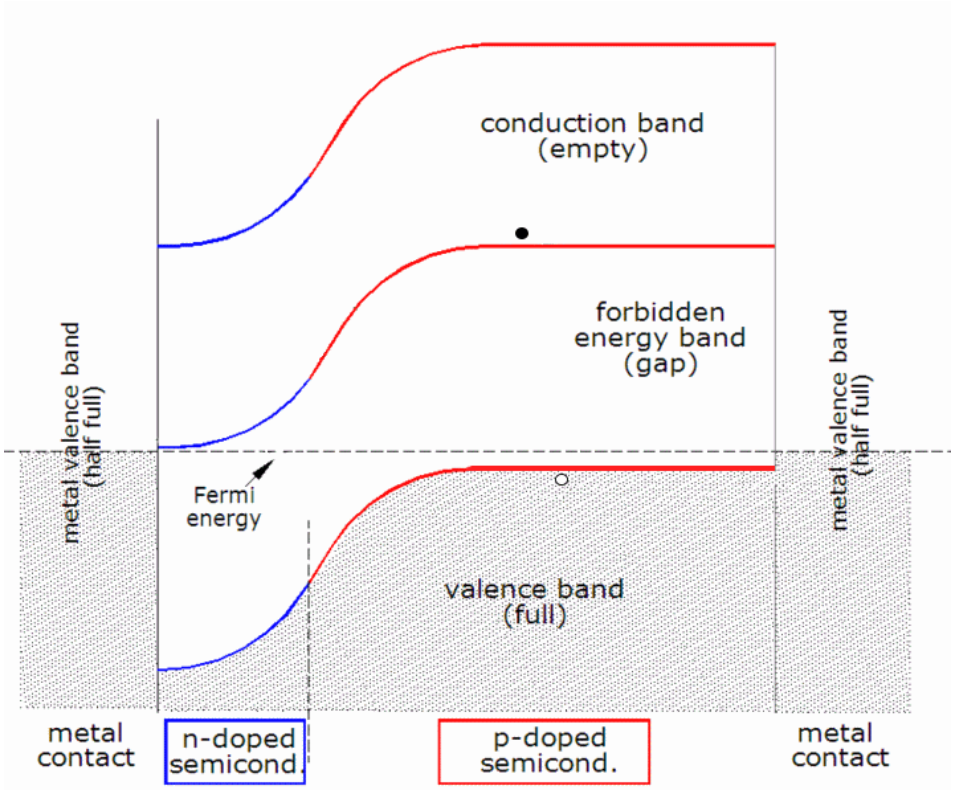

- $E_\gamma < E_g$: ☹

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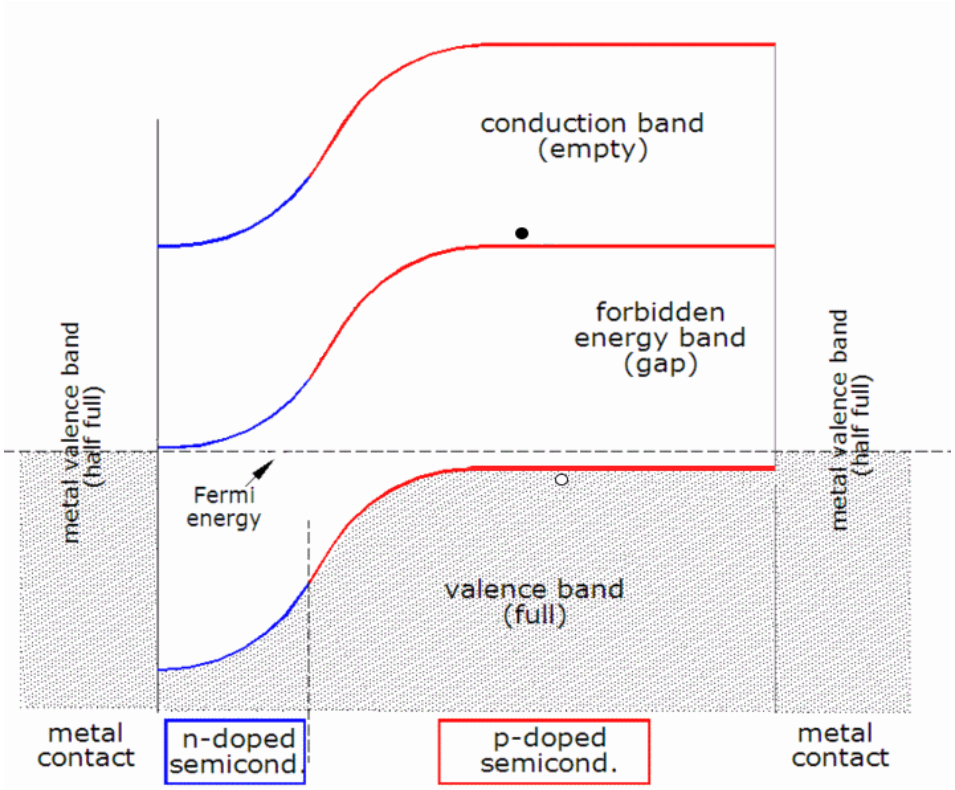

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- $E_\gamma = E_g$: ⚡

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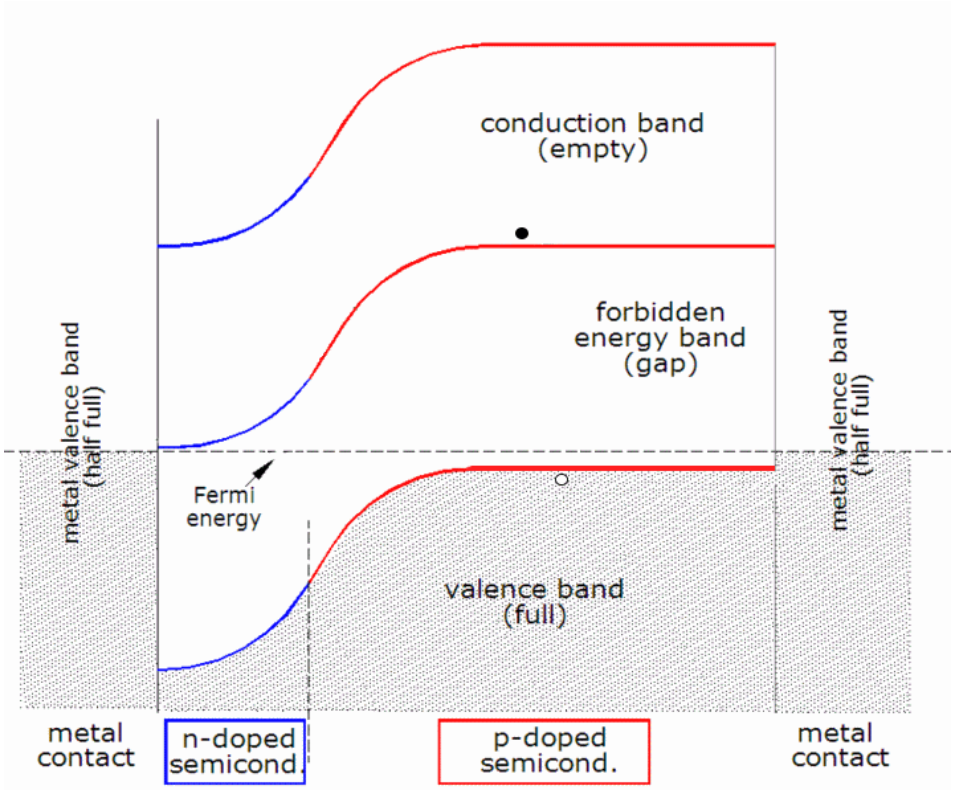

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- $E_\gamma > E_g$: ⚡ + 🔥

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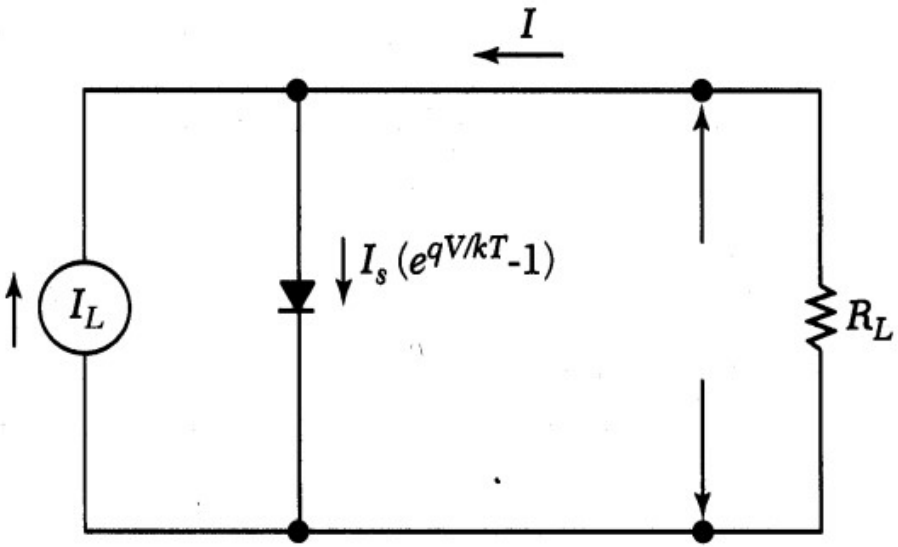

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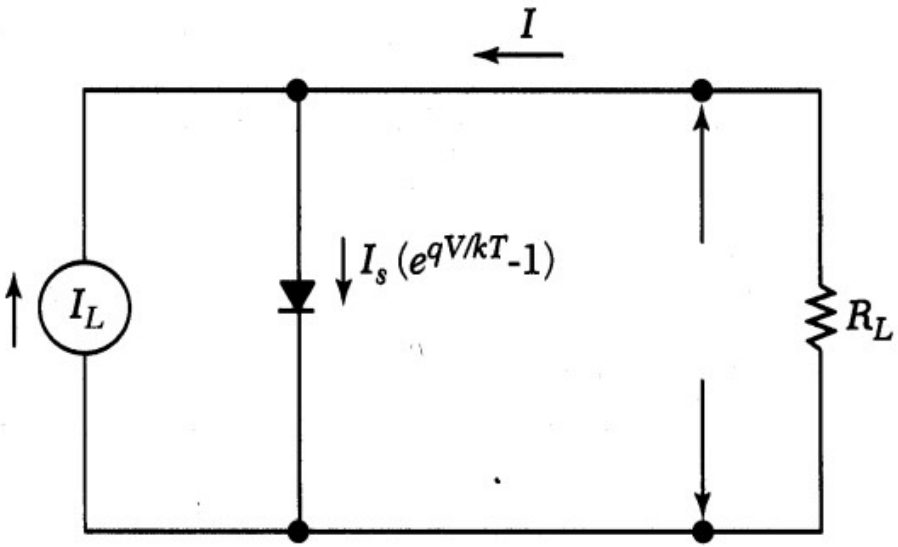

= current source in parallell I_L

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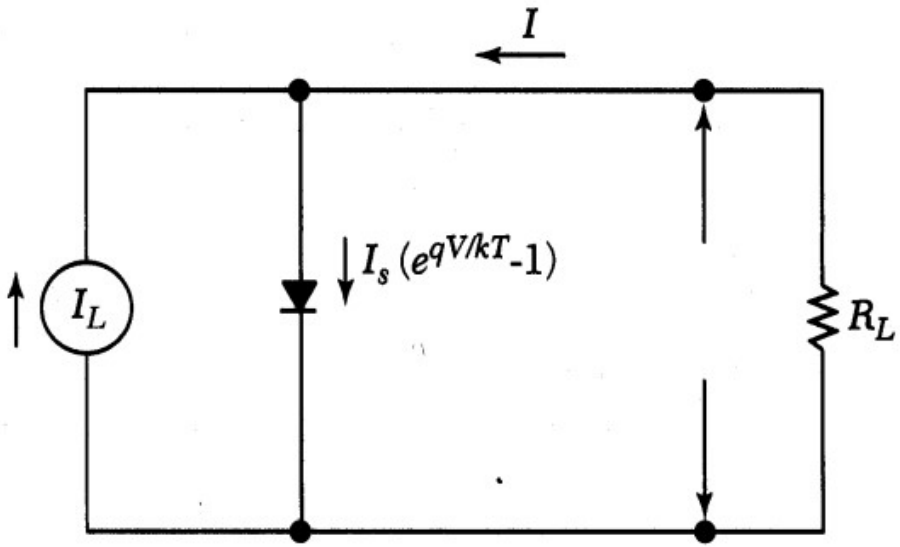

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$$\Longrightarrow I = I_S(e^{qV/kT} - 1) - I_L$$

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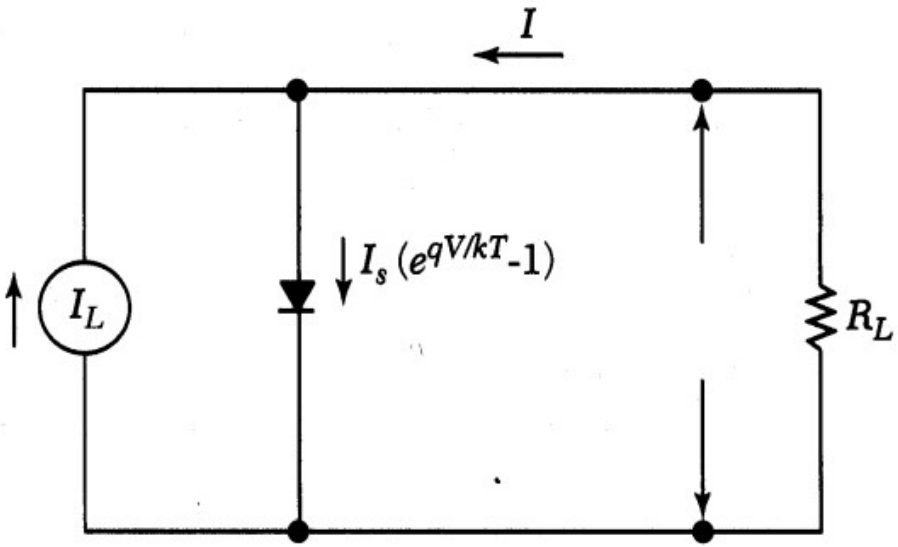

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$\downarrow$ depends on E_g

$\downarrow$ depends on N_{ph} with $h\nu > E_g$

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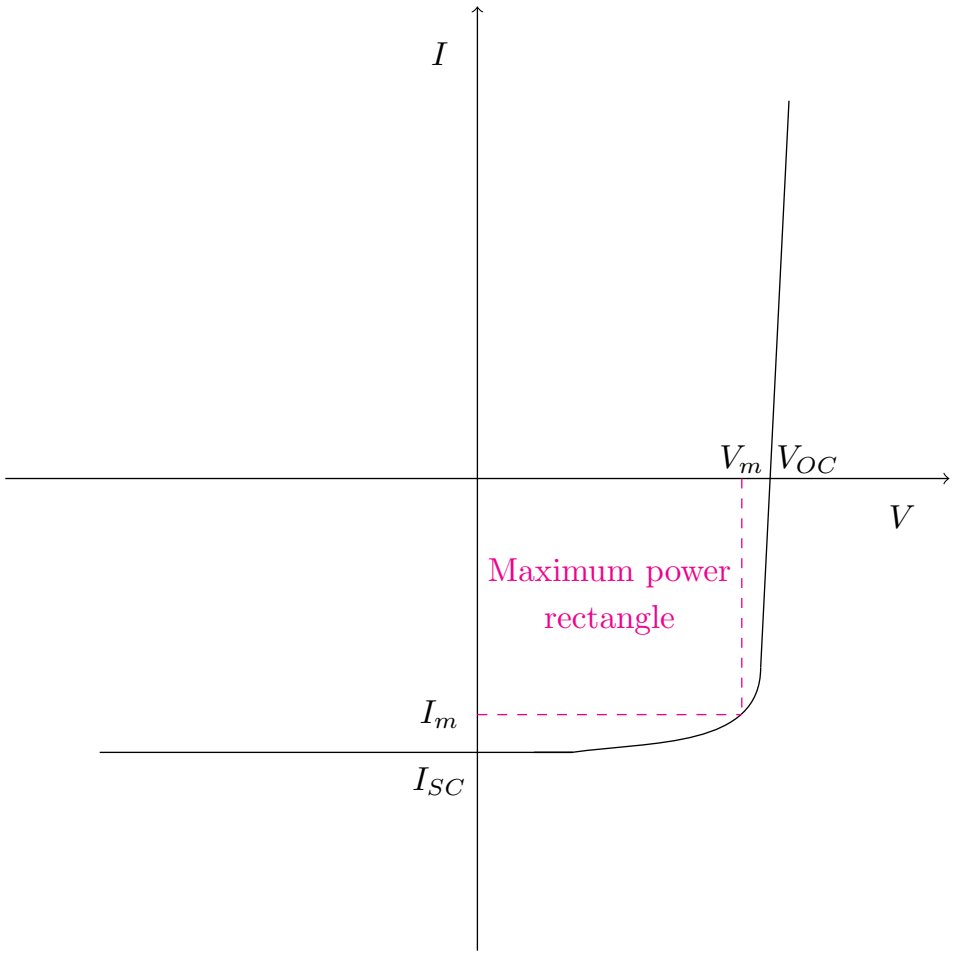

V_{OC} : open circuit voltage ($R \to \infty$)
I_{SC} : short circuit current ($R = 0$)

$\Longrightarrow$ Maximum power:
$P_m = I_m V_m$

Efficiency of an ideal solar cell

$$\eta = FF \frac{I_L V_{OC}}{P_{in}}$$

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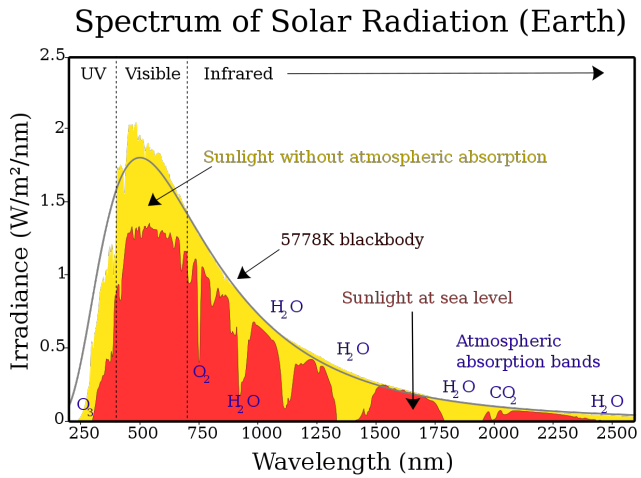

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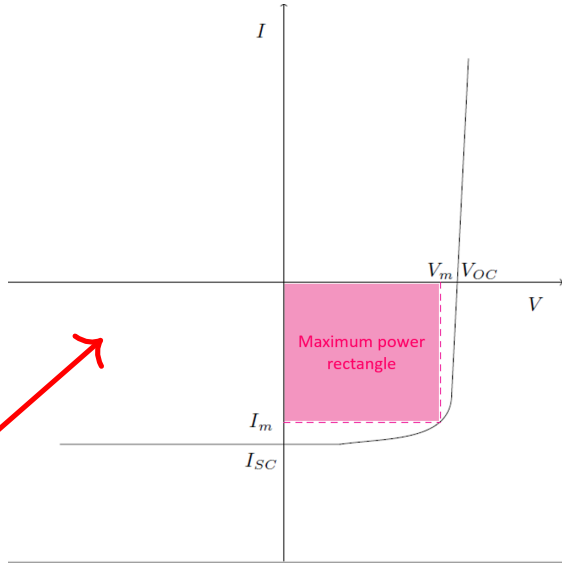

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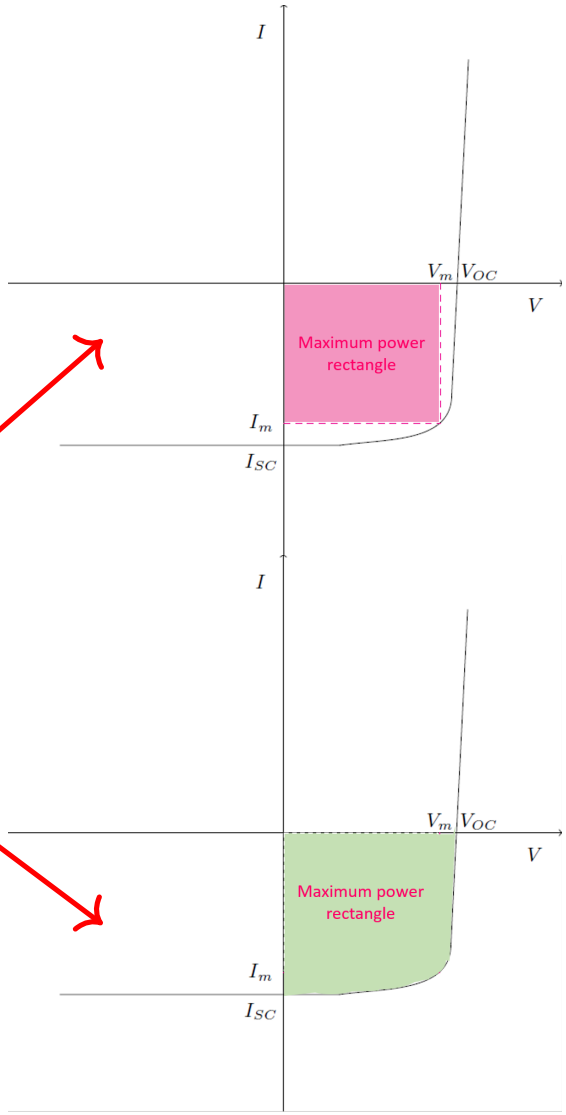

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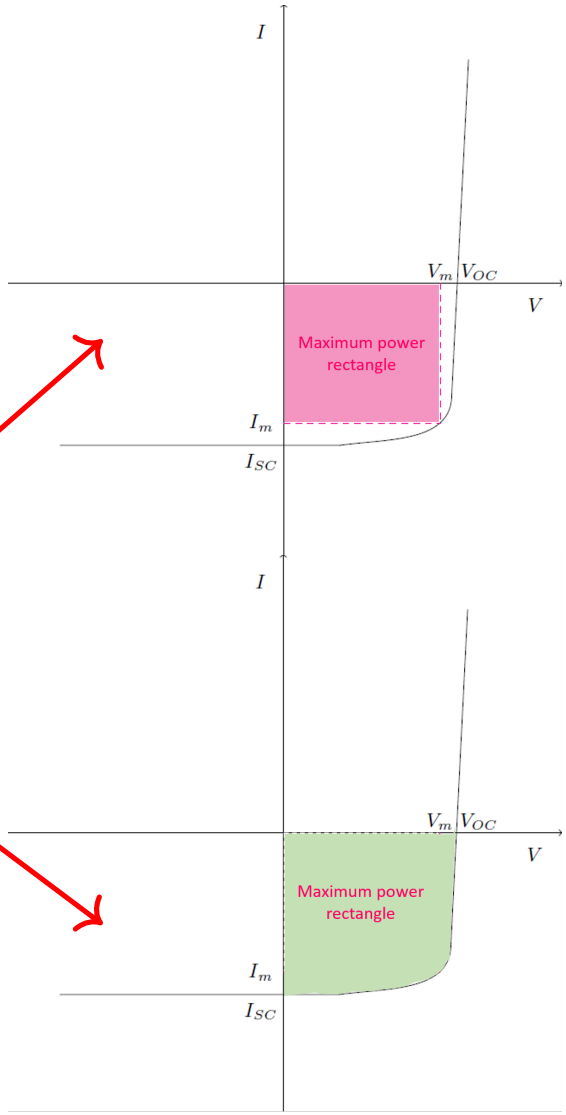

AM 1.5 : $\eta \sim 29\%$
(ideal)

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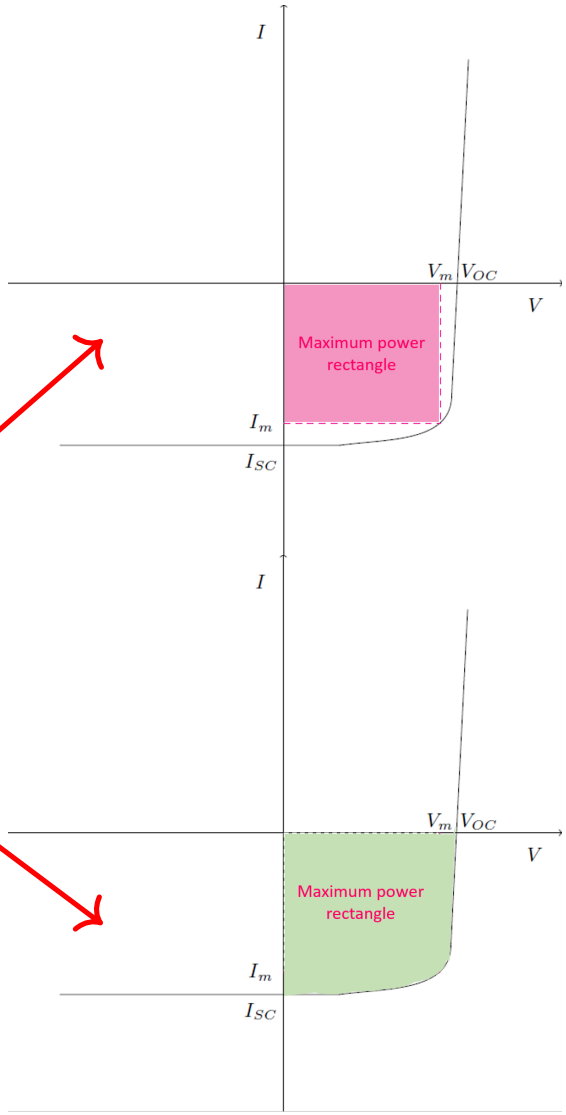

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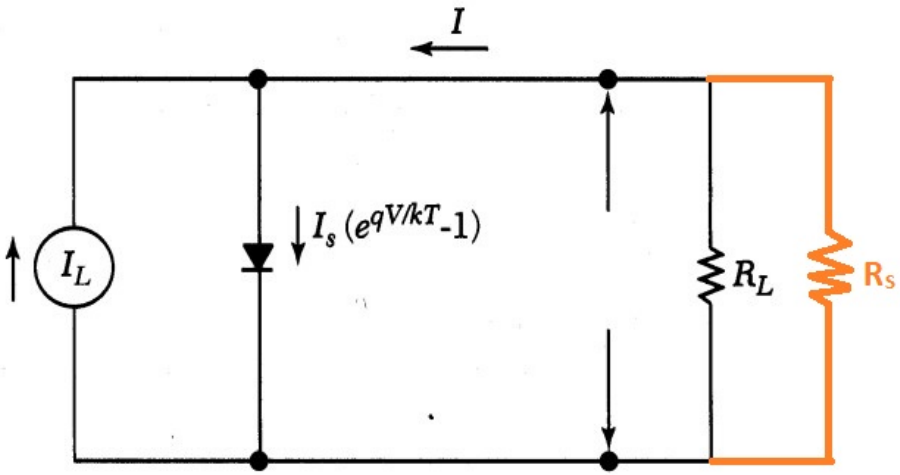
$10 - 15\%$

Efficiency loss: serie resistance



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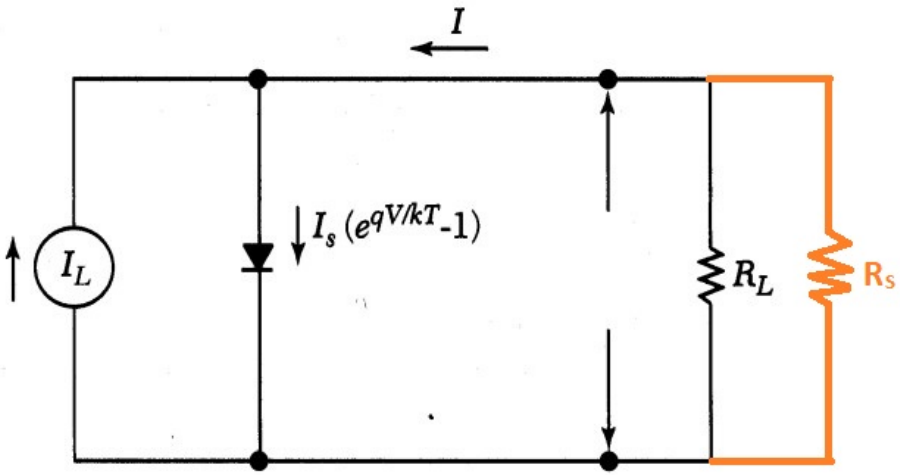

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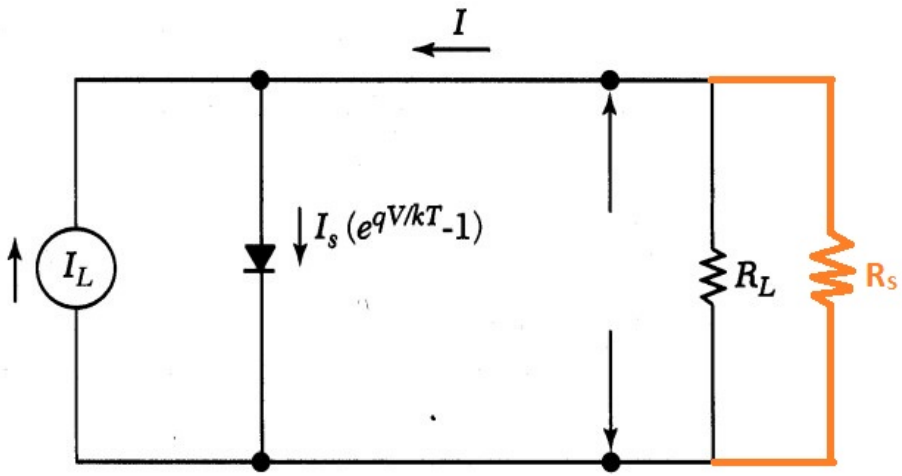

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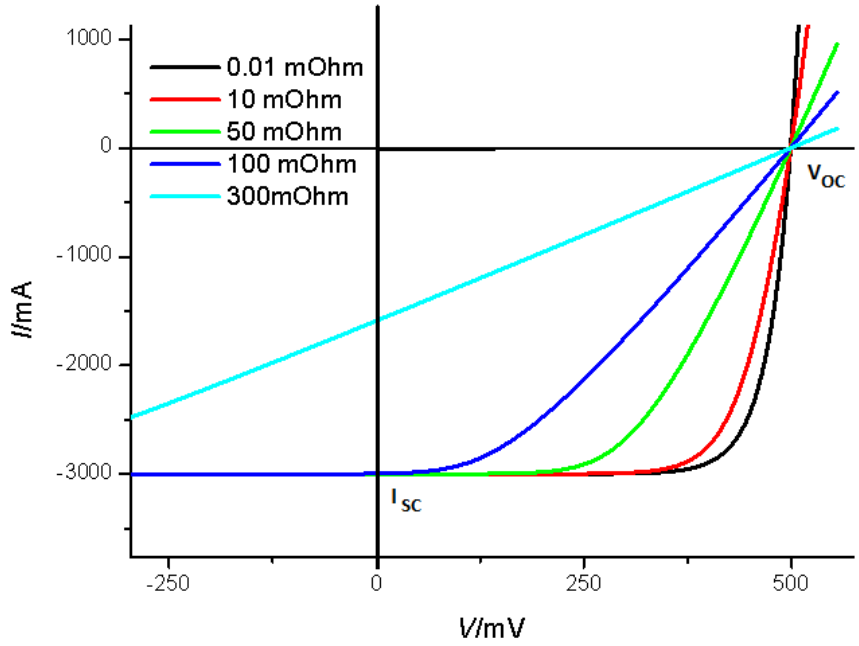

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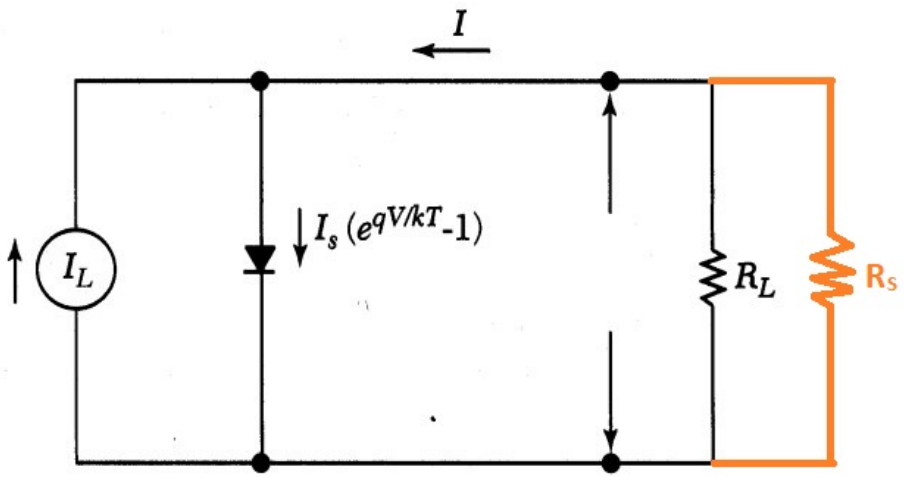
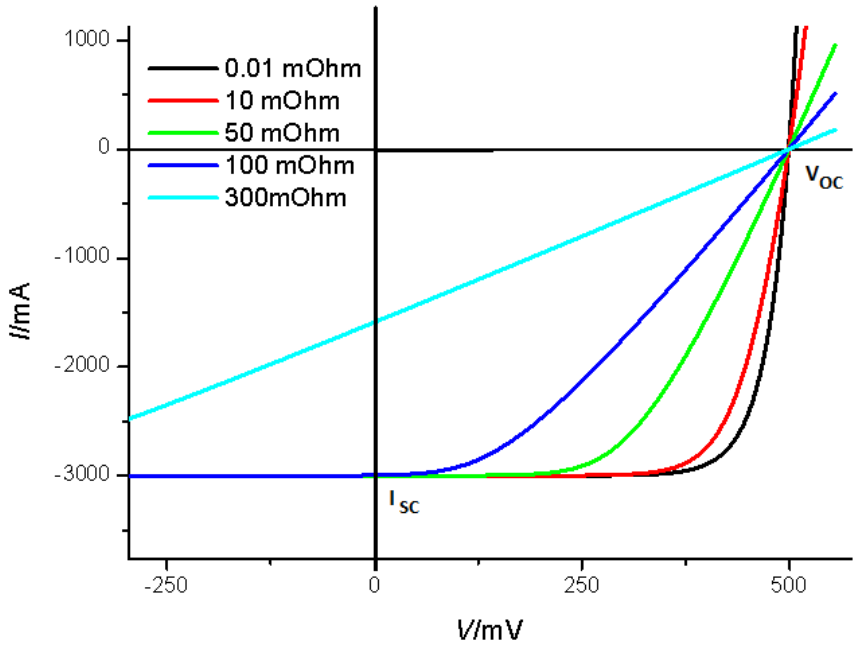
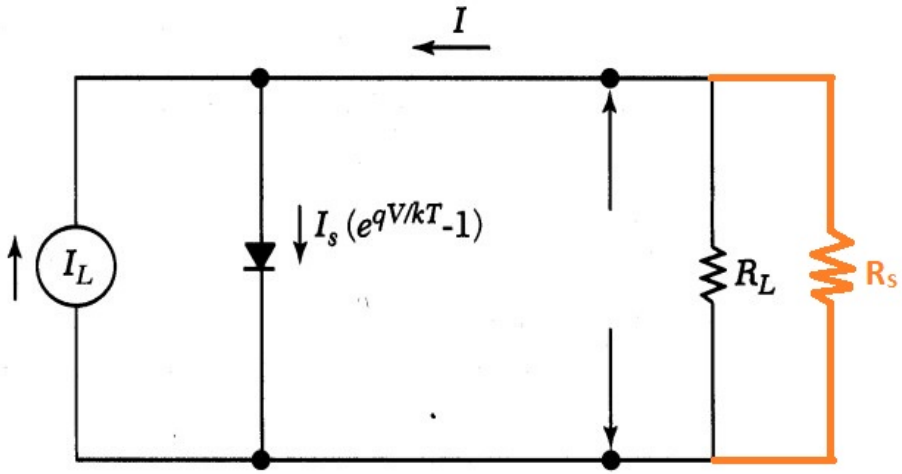


$$\Longrightarrow I = I_S(e^{q(V-IR_S)/kT} - 1) - I_L$$



Serie resistance: $\eta_{id} \rightarrow 60\%\eta_{id}$

Efficiency loss: serie resistance



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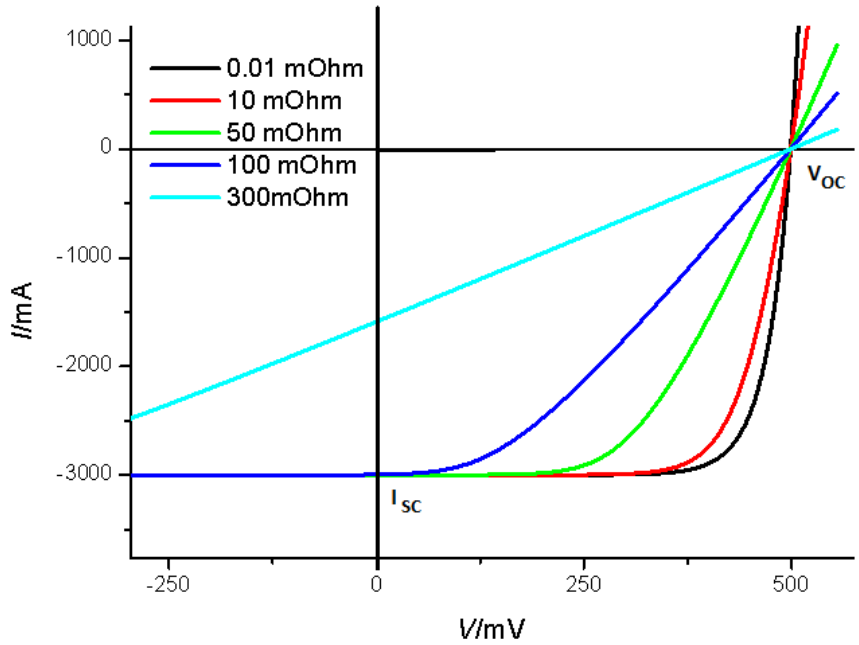
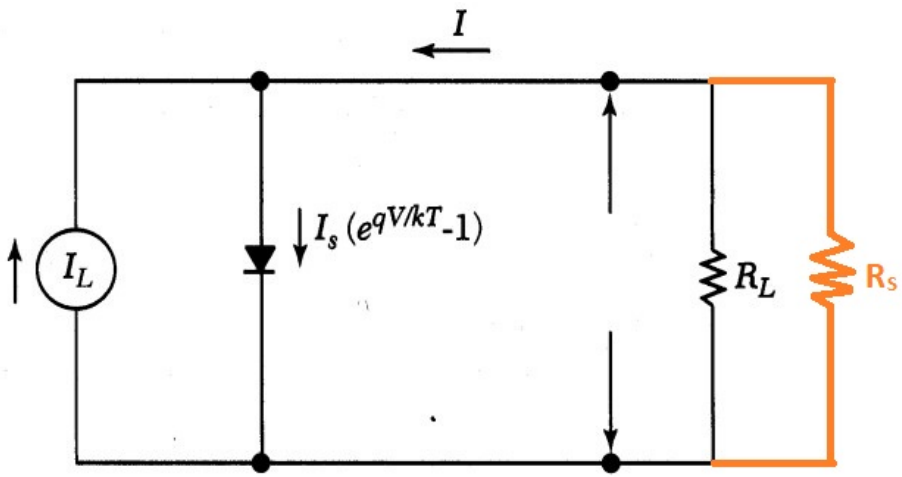
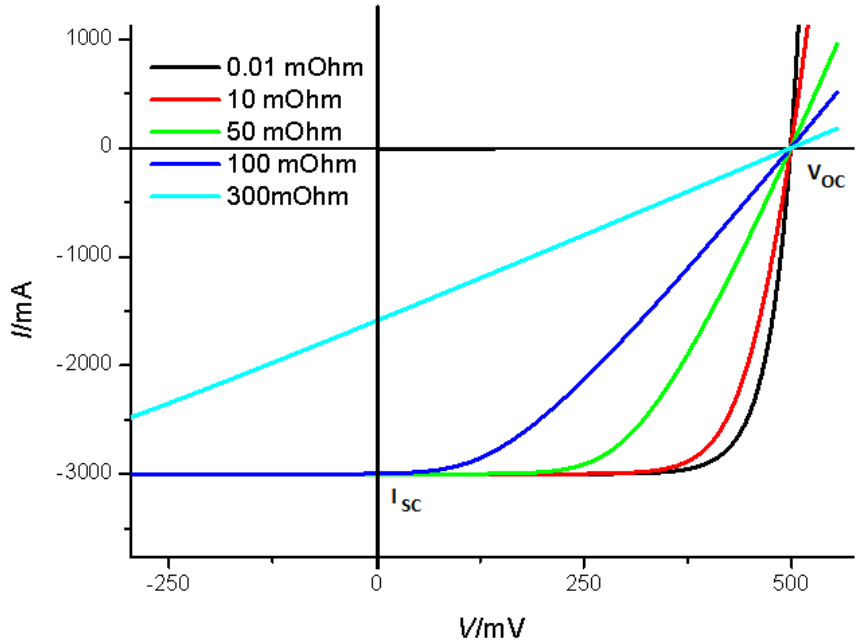


Serie resistance: $\eta_{id} \rightarrow 60\%\eta_{id}$
Recombination current: $\eta_{id} \rightarrow 75\%\eta_{id}$

Efficiency loss: serie resistance



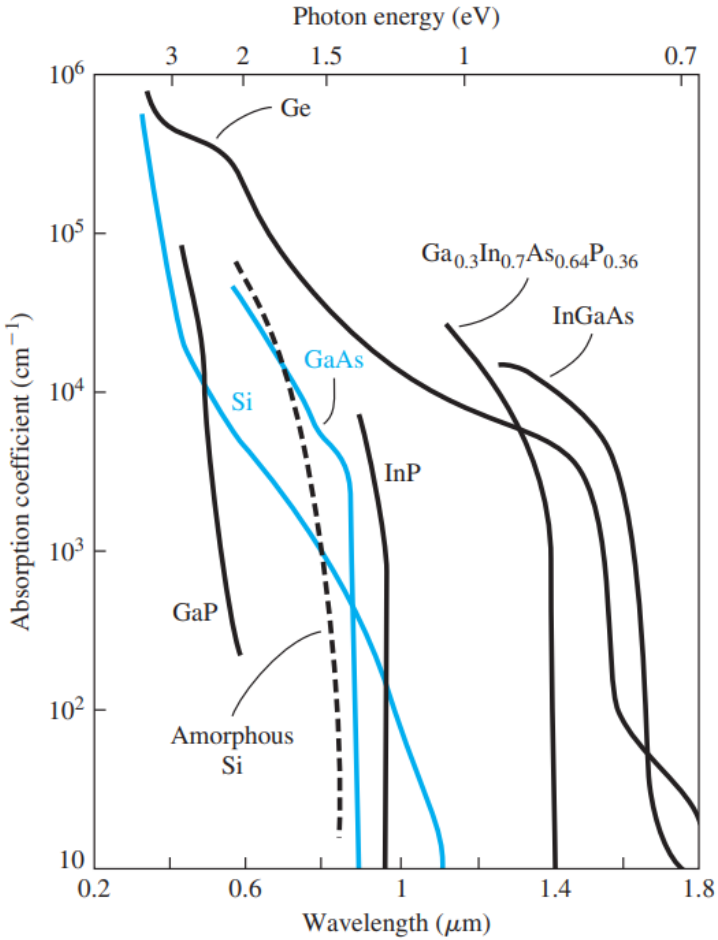
$$\Longrightarrow I = I_S(e^{q(V-IR_S)/kT} - 1) - I_L$$

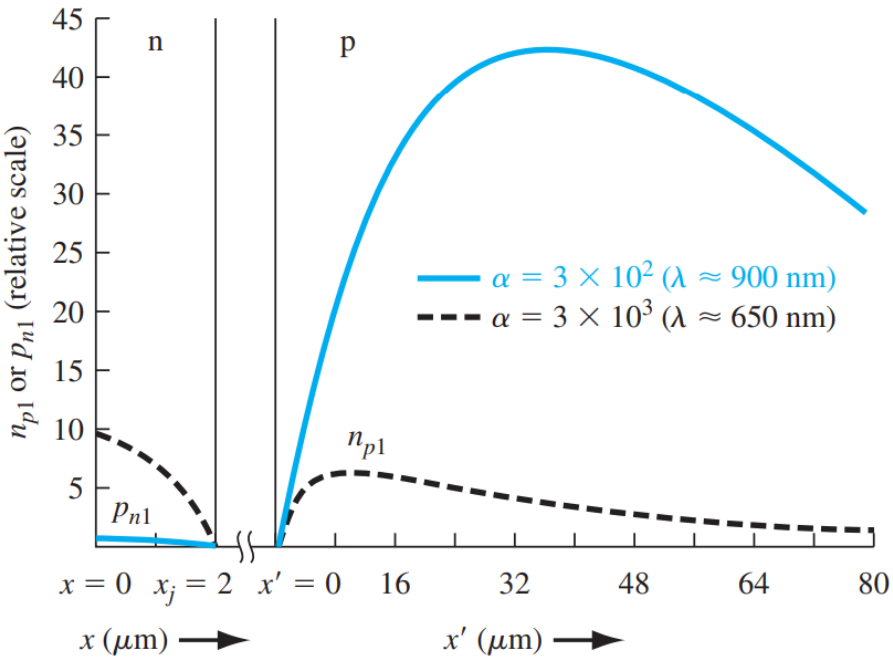


Serie resistance: $\eta_{id} \rightarrow 60\%\eta_{id}$
Recombination current: $\eta_{id} \rightarrow 75\%\eta_{id}$
Total: $\eta_{id} \rightarrow 45\%\eta_{id}$

Efficiency loss: non-uniform absorption

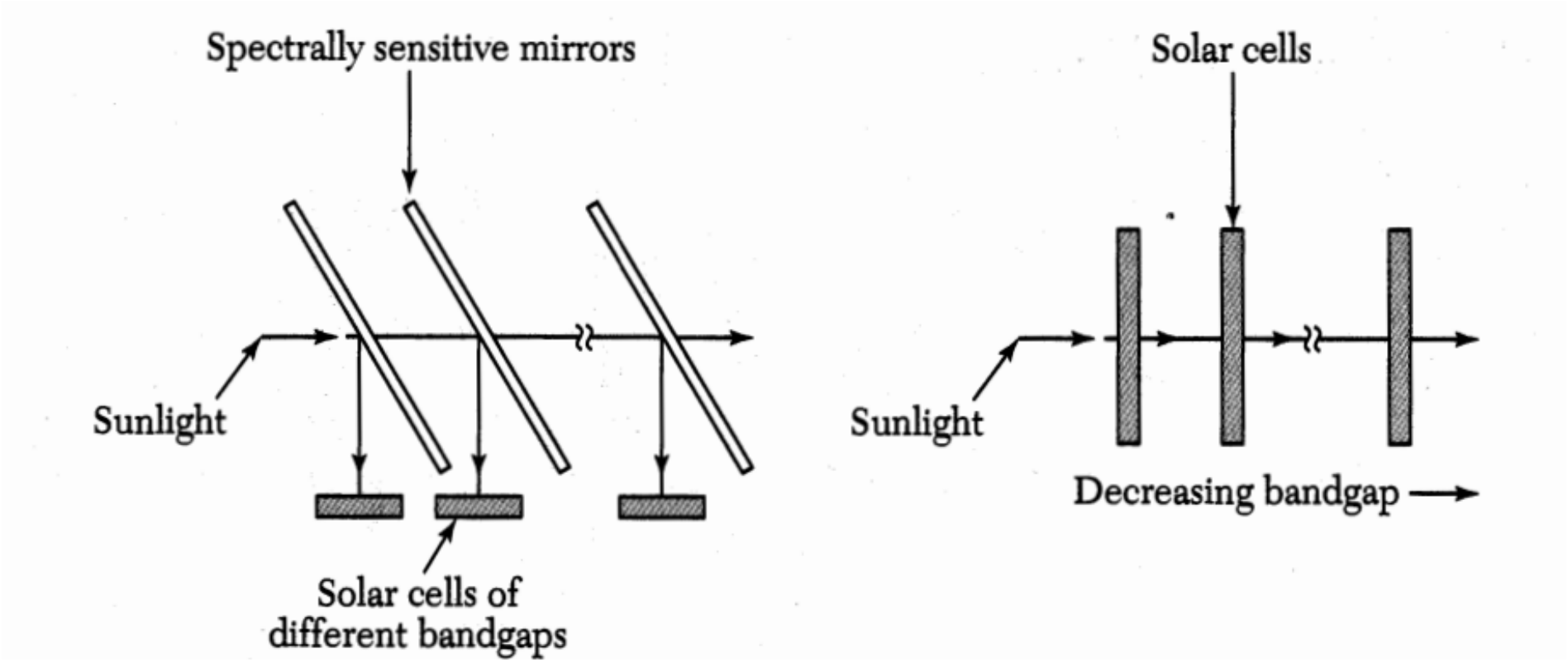
$$G_L(\lambda, x) = \alpha(\lambda)\phi(\lambda)[1 - R(\lambda)]e^{-\alpha(\lambda)x}$$





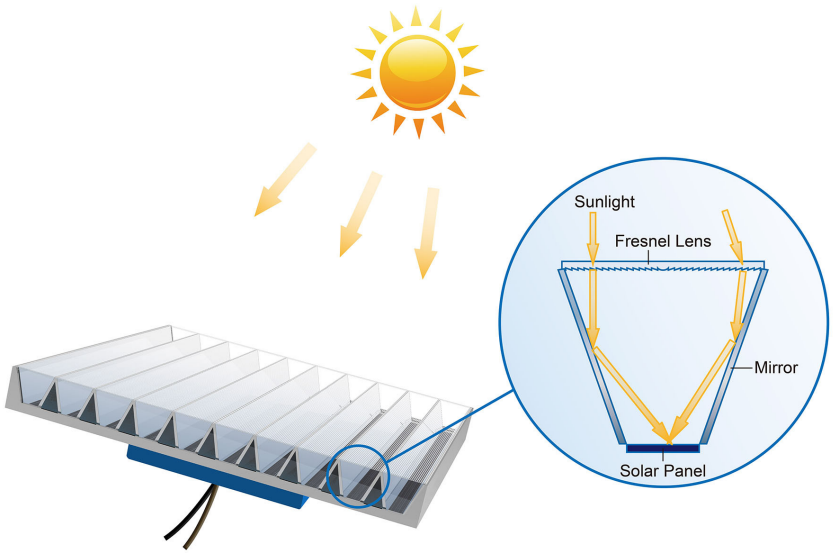
Efficiency gain: spectrum splitting

Idea: increase $P_i \rightarrow$ reduce the wavelength range



Efficiency gain: optical lensing

Idea: increase light concentration



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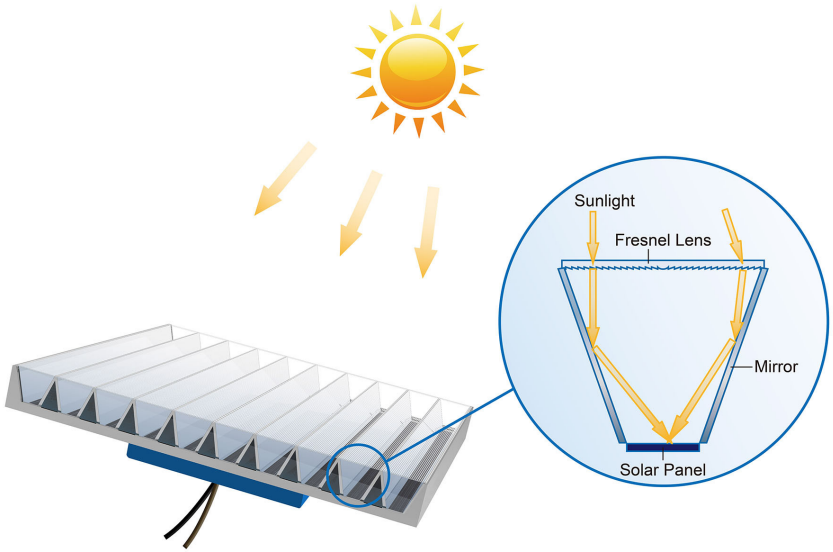
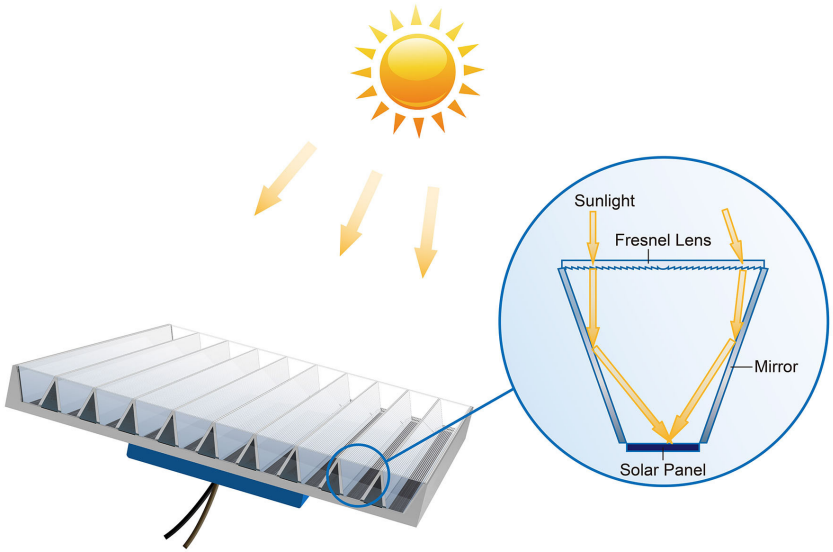


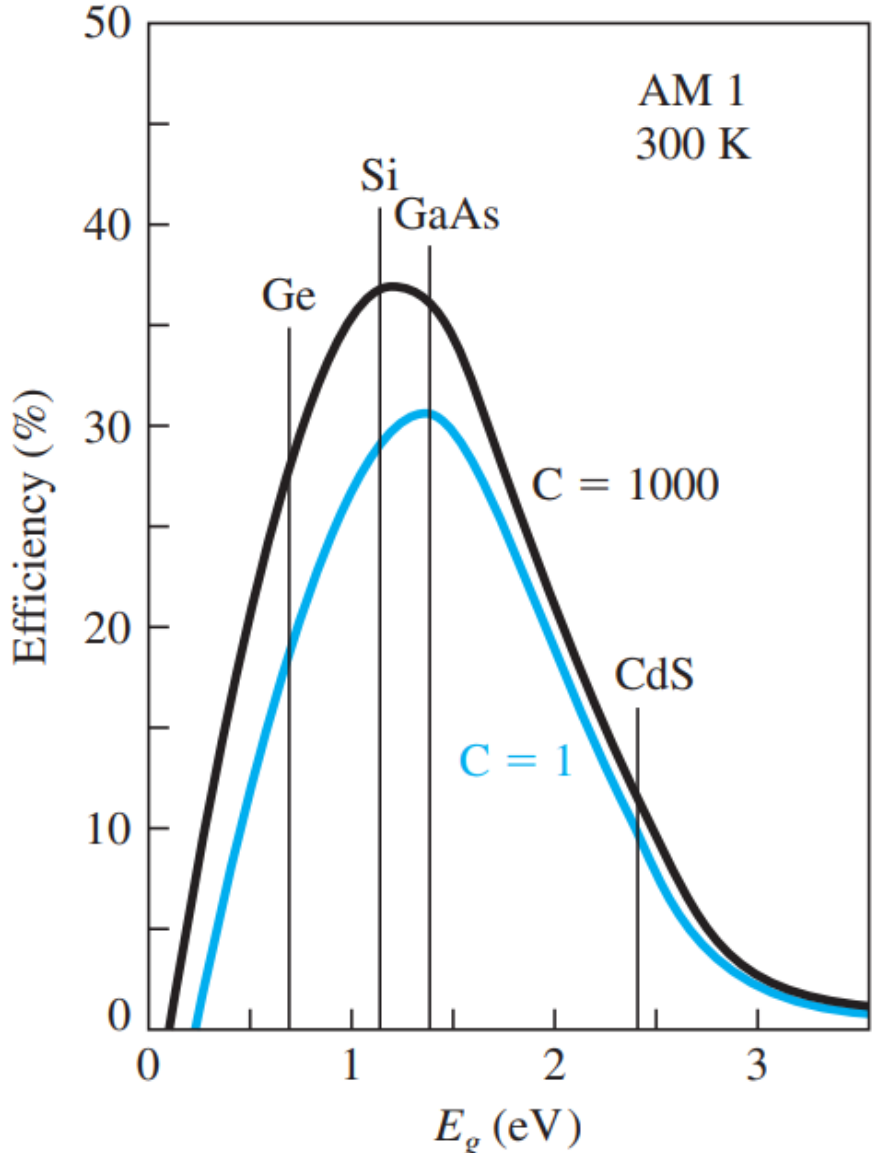
At $C = 1000 : \eta_{id} \rightarrow 130\% \eta_{id}$

Efficiency gain: optical lensing

Idea: increase light concentration



At $C = 1000 : \eta_{id} \rightarrow 130\% \eta_{id}$



Different types of solar cells

- Monocrystalline: pure silicon, single crystal
- Policrystalline: liquid silicon subjected to solidifaction process, many crystal of different sizes
- Amorphous: silicon deposited on a substrate, e.g. glass plate

	Monocrystalline	Policrystalline	Amorphous
Efficiency	14%-18%	12%-14%	5%-6%
Lifespan	25-30 years	20-25 years	15-20 years
Cost	Very expensive	Expensive	Cheap

Applications

Applications

Applications

Applications

Summary - solar cells

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- **Efficiency** of an ideal solar cells depends on the maximum and input power; it is degraded by **serie resistance** and **non-uniform absorption**, while it can be increased by **splitting** the spectrum or **focusing** the solar radiation.
- There are **different types** of solar cells depending on the type of the crystal used
- **Applications** of solar cells can be found in different devices

Summary - photo-diodes

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Summary - photo-diodes

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Summary - final

References

[1] Donald A Neamen. *Semiconductor physics and devices: basic principles*. McGraw-hill, 2003.

[2] Simon M Sze, Yiming Li, and Kwok K Ng. *Physics of semiconductor devices*. John wiley & sons, 2021.

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