جامعة مولاي إسماعيل
ⵜⴰⵙⴷⴰⵡⵉⵜ ⵎⵓⵍⴰⵢ ⵉⵙⵎⴰⵄⵉⵍ
UNIVERSITÉ MOULAY ISMAÏL

كلية العلوم
ⵜⴰⵖⵡⴰⵍⵜ ⵏ ⵜⵣⵔⴼⵜ
FACULTÉ DES SCIENCES

Course Optoelectronic

Parcours électronique S6
2025-2026

Pr. Omar EL OUTASSI

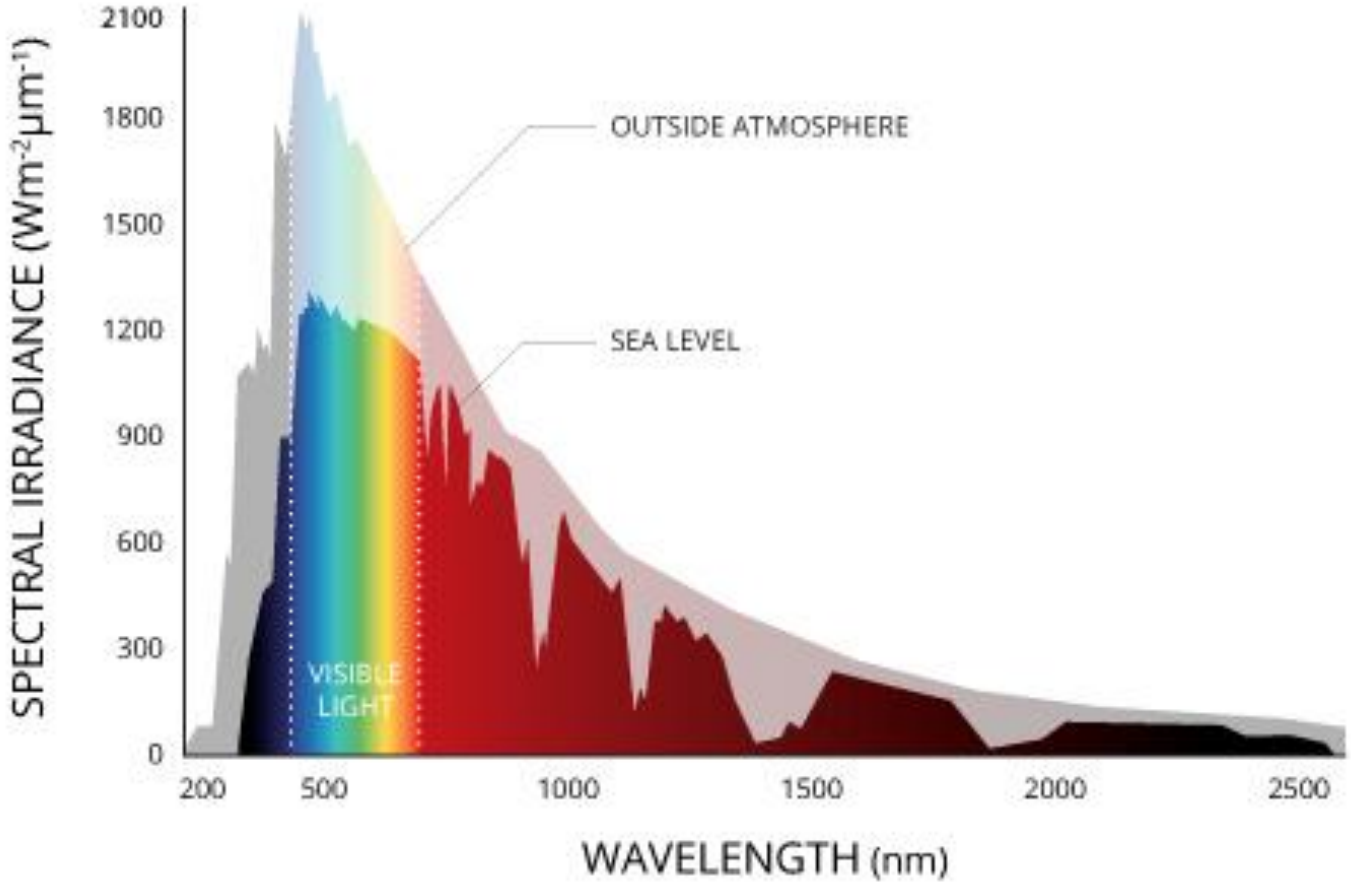
Chapitre 4: : Photovoltaic devices

- Explain Solar Energy Spectrum
- Describe device principles of Solar cell
- Understand I-V characteristics of Photovoltaic devices
- Understand equivalent circuits
- Explain efficiencies of photovoltaic devices

Pr. Omar EL OUTASSI
o.eloutassi@umi.ac.ma

Solar Energy Spectrum

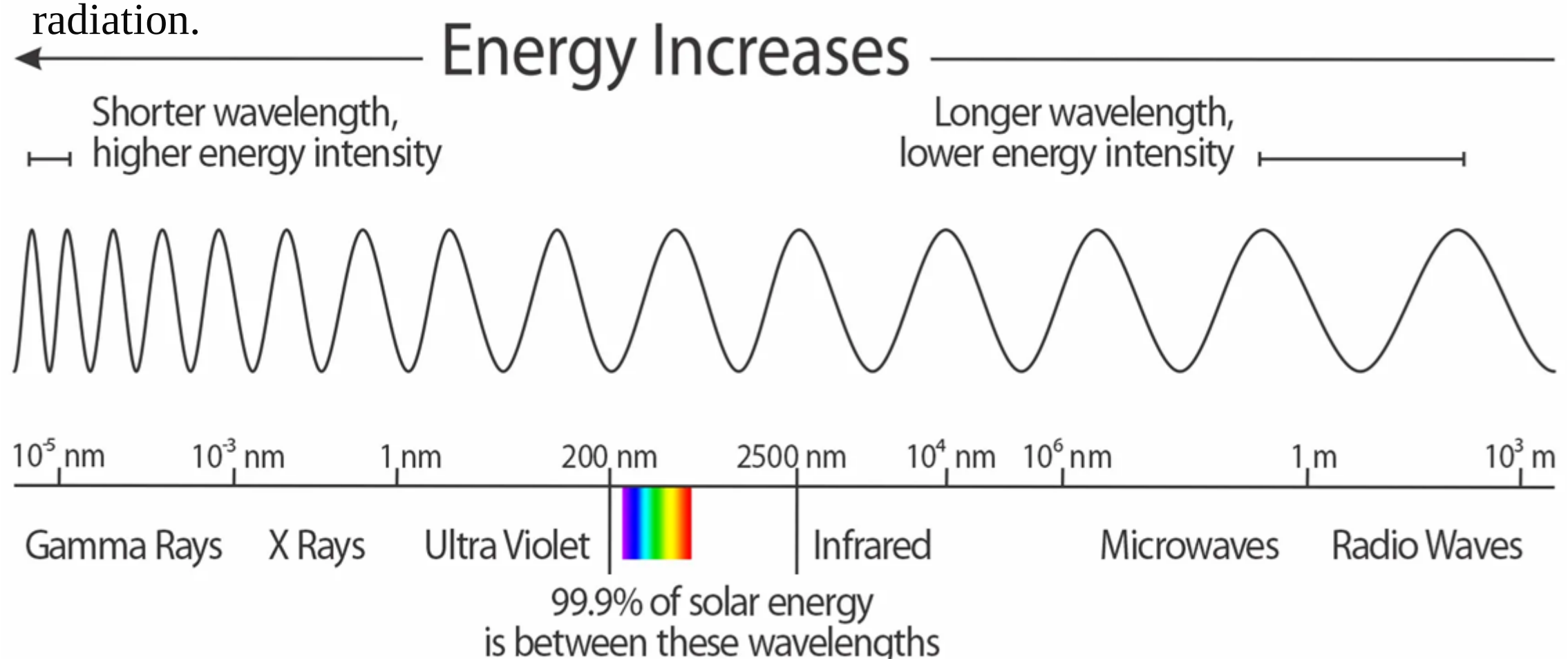
Describes the distribution of electromagnetic radiation emitted by the sun, which can be modeled as a **black body** with a surface temperature of approximately 5800 K.



Pr. Omar EL OUTASSI
o.eloutassi@umi.ac.ma

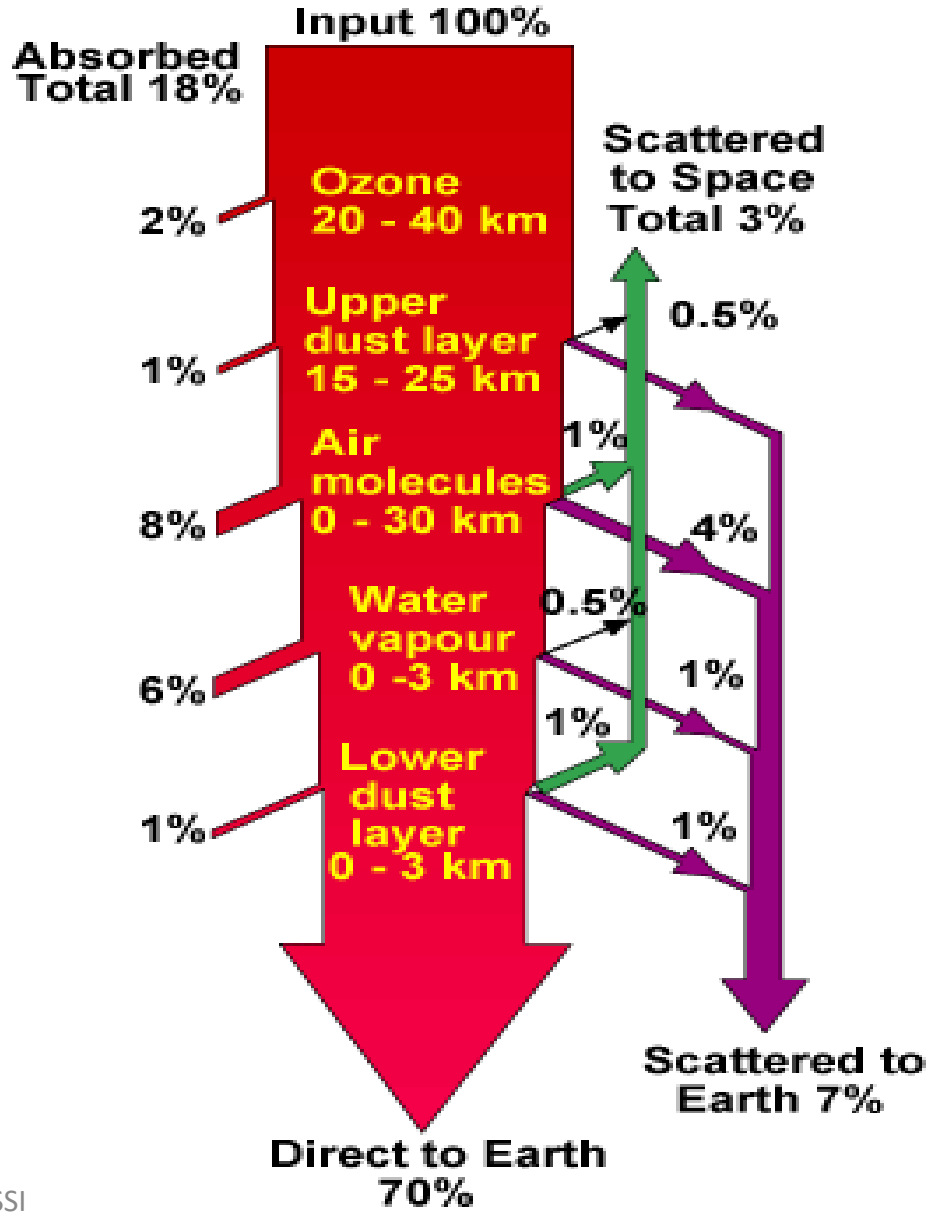
Solar Energy Spectrum

- **Composition:** The spectrum includes ultraviolet (UV), visible light, and infrared (IR) radiation.



Solar Energy Spectrum

- **Atmospheric Effects:** As sunlight passes through the atmosphere, it undergoes :
  - Absorption by molecules like water vapor and CO_2 (creating dark Fraunhofer lines)
  - Scattering by air and dust, which changes the spectral distribution that reaches the Earth's surface.



Pr. Omar EL OUTASSI
o.eloutassi@umi.ac.ma

Solar Energy Spectrum

- **Air Mass (AM):** A parameter defining the path length of sunlight through the atmosphere. The standard for terrestrial solar panel testing is the AM1.5 spectrum, which integrates to 1000 W/m².

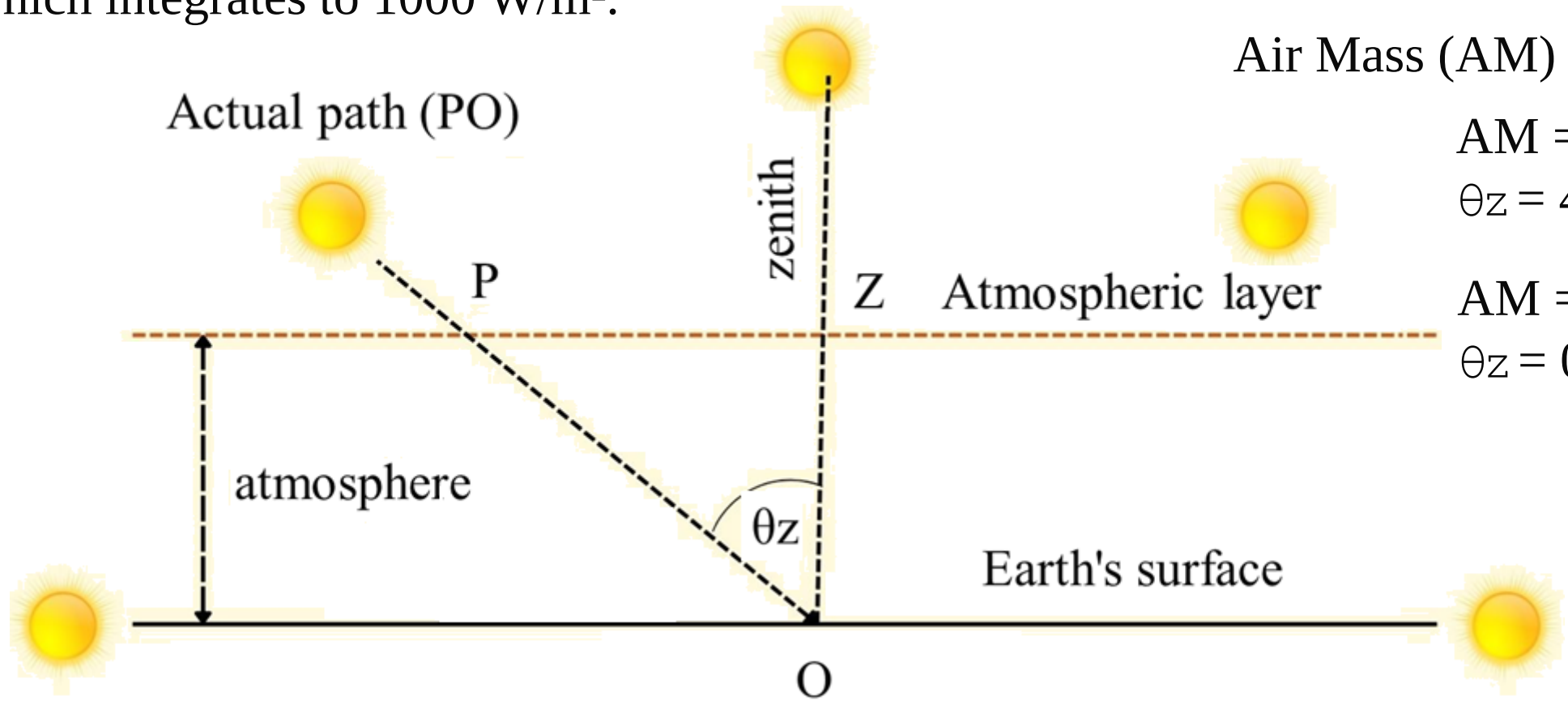
Air Mass (AM) = PO/ZO

AM =1.5

θz = 48.2°

AM =1

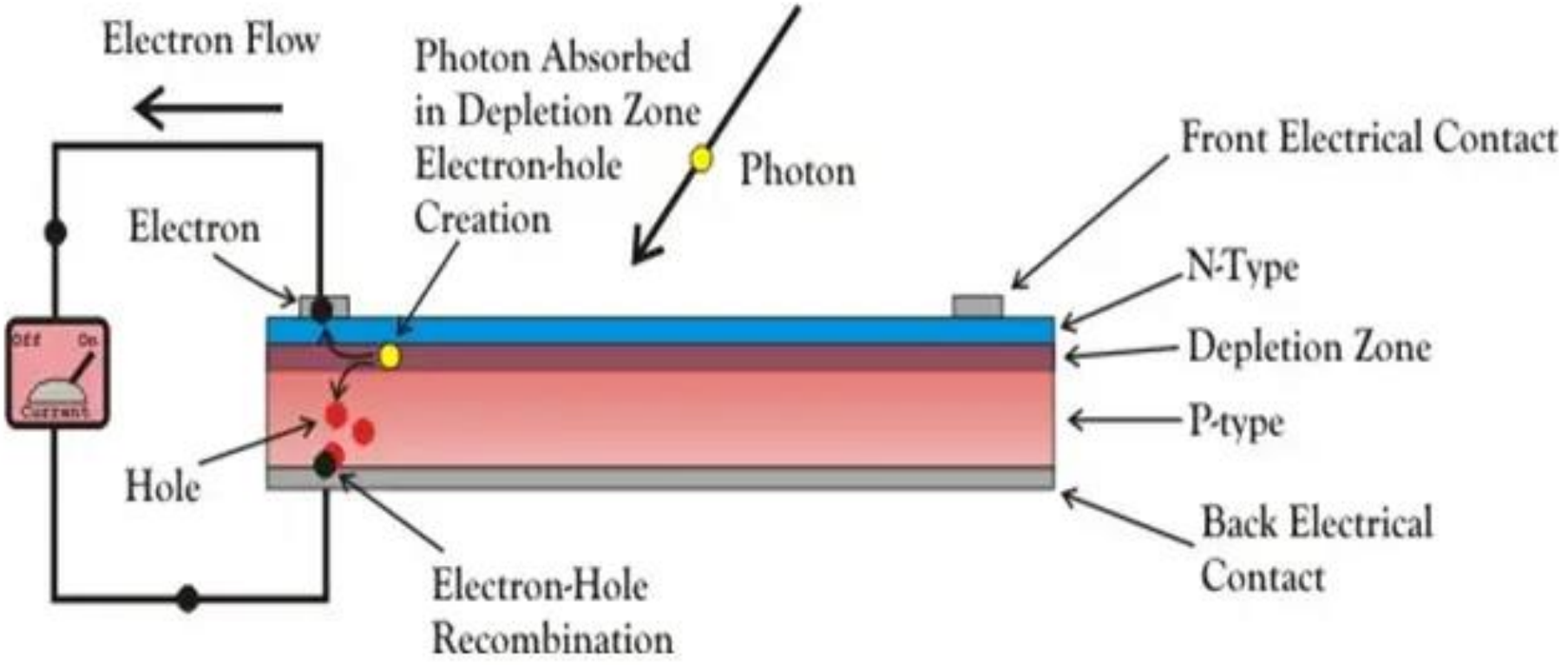
θz = 0°



Pr. Omar EL OUTASSI
o.eloutassi@umi.ac.ma

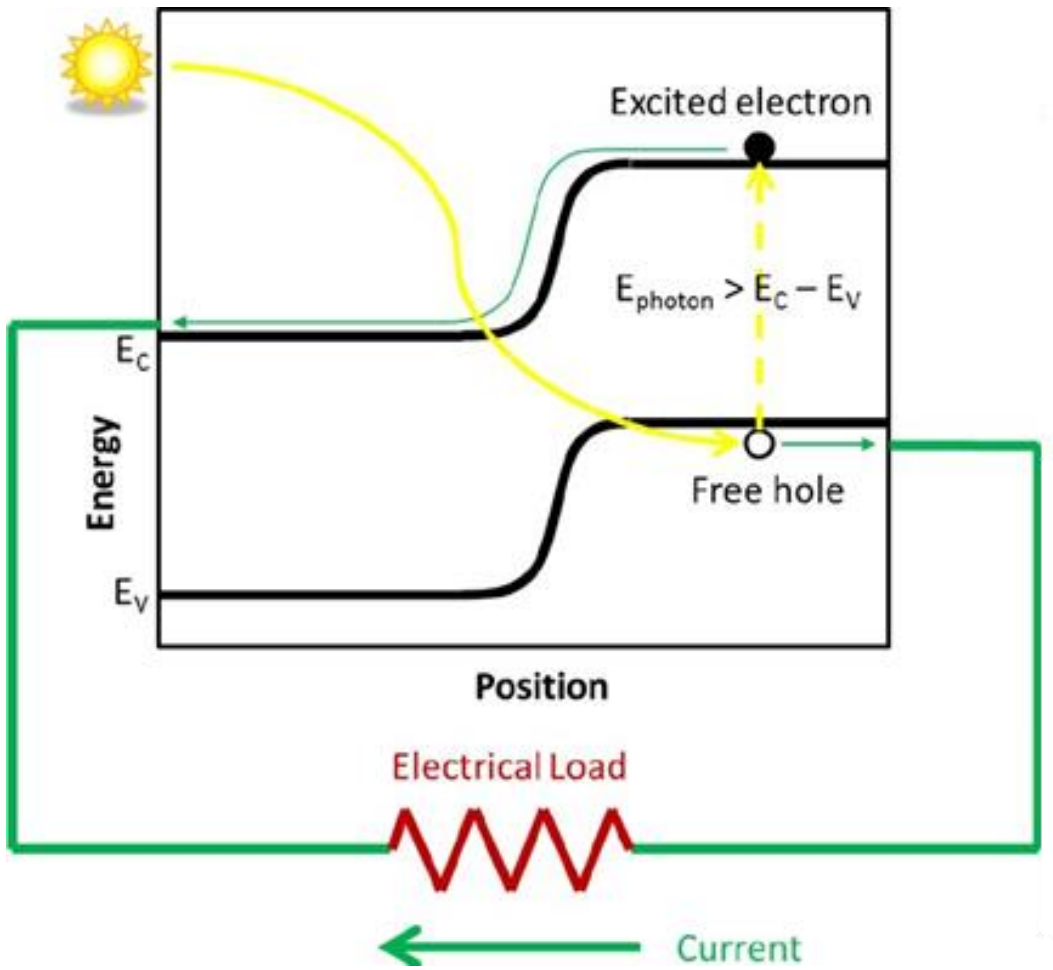
Device principles of Solar cell

A solar cell (or photovoltaic cell) is an electrical device that converts light energy directly into electrical energy using the **photovoltaic effect**. This effect involves three key steps:



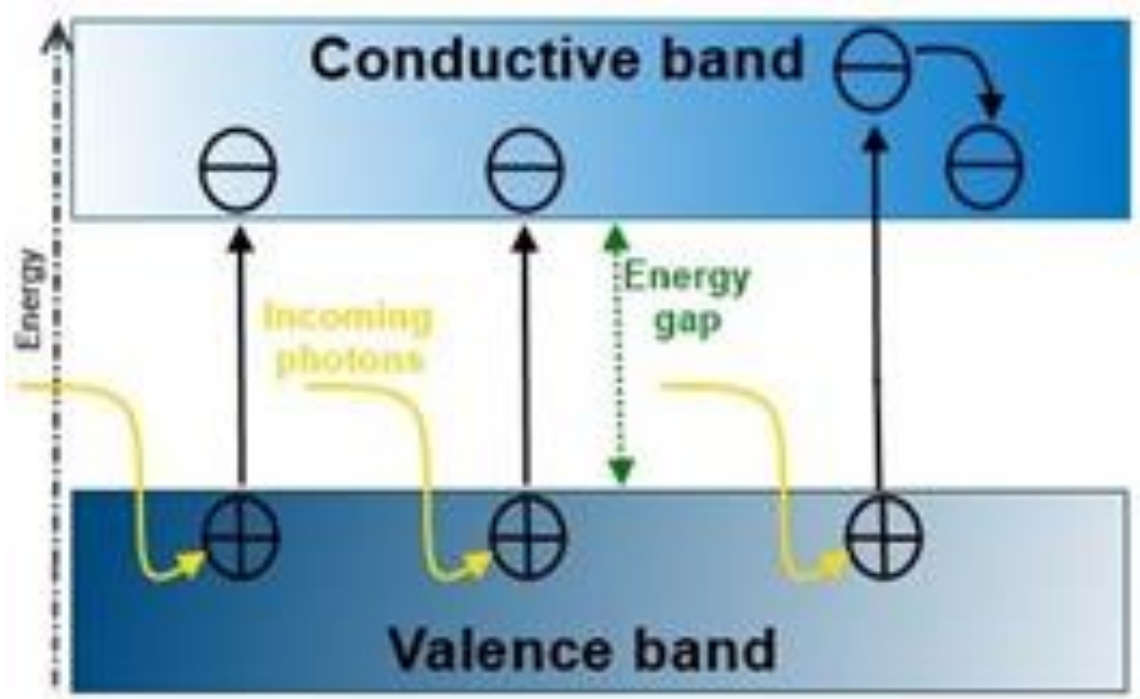
Device principles of Solar cell

- **Light Absorption:** Photons from sunlight strike the semiconductor material (e.g., silicon) and are absorbed if their energy is equal to or greater than the material's band gap.



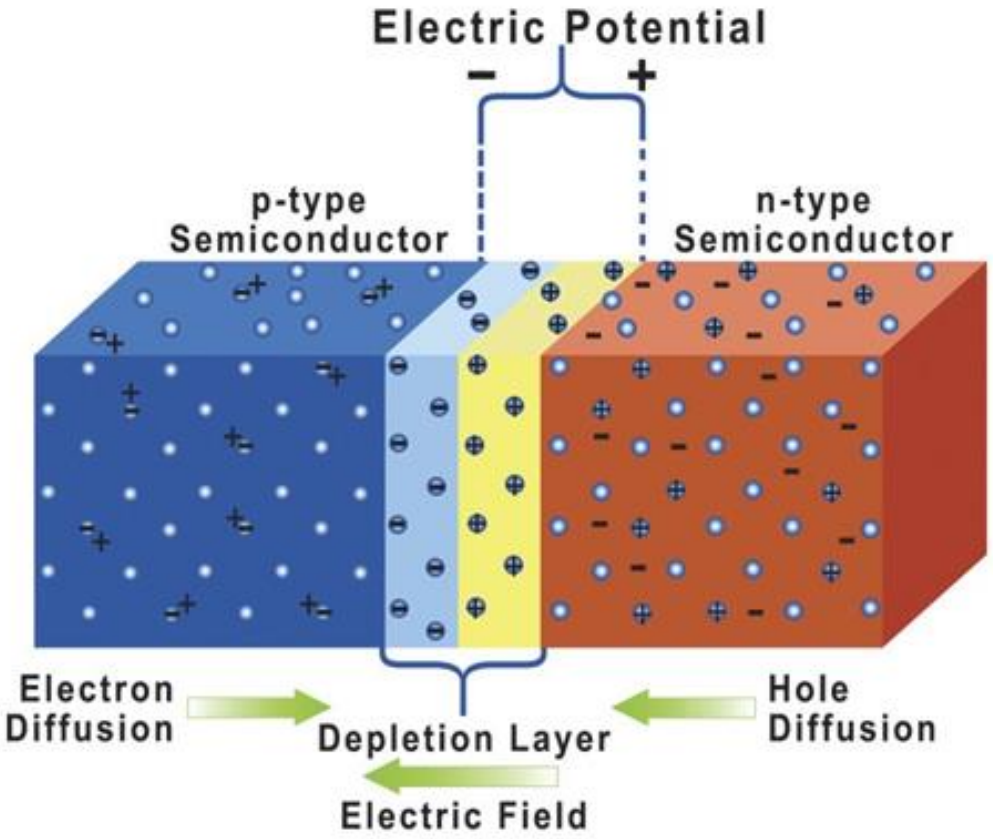
Device principles of Solar cell

- **Charge Carrier Generation:** The absorbed photon energy excites an electron from the valence band to the conduction band, creating a free electron and a "hole" (a missing electron, acting as a positive charge carrier).



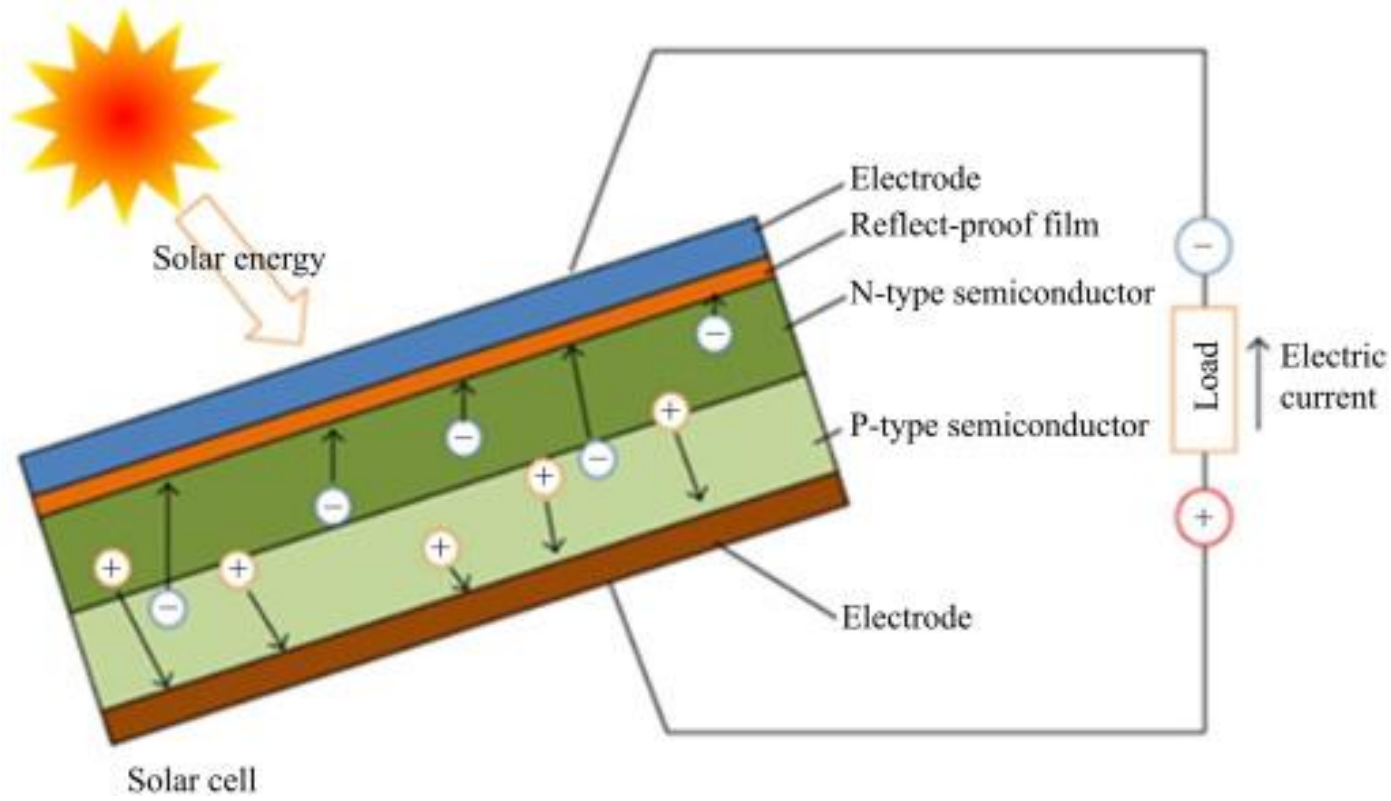
Device principles of Solar cell

- **Charge Separation:** An internal electric field (built into the p-n junction of the semiconductor) forces the negatively charged electrons to the n-type side and the positively charged holes to the p-type side. This prevents them from quickly recombining.



Device principles of Solar cell

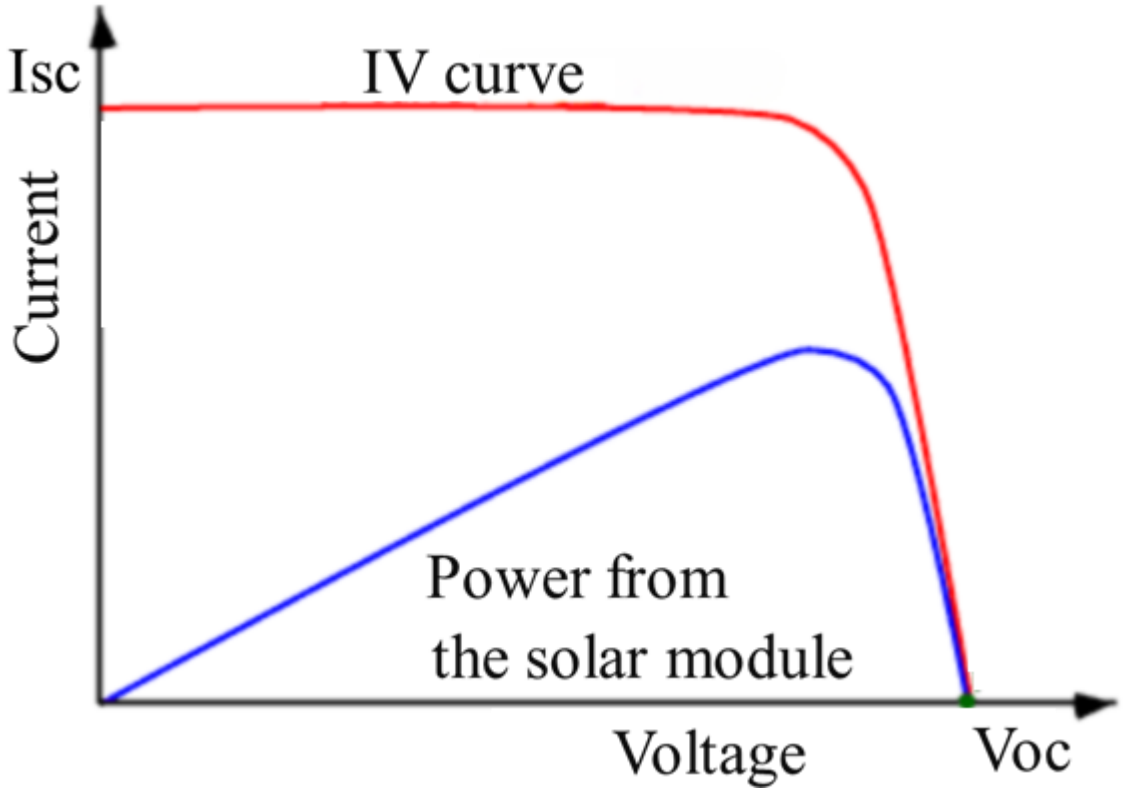
- **Collection:** Metallic contacts on the surfaces collect these separated charges, creating a potential difference (voltage). When an external load is connected, the electrons flow through the circuit, performing work as an electric current.



I-V characteristics of Photovoltaic devices

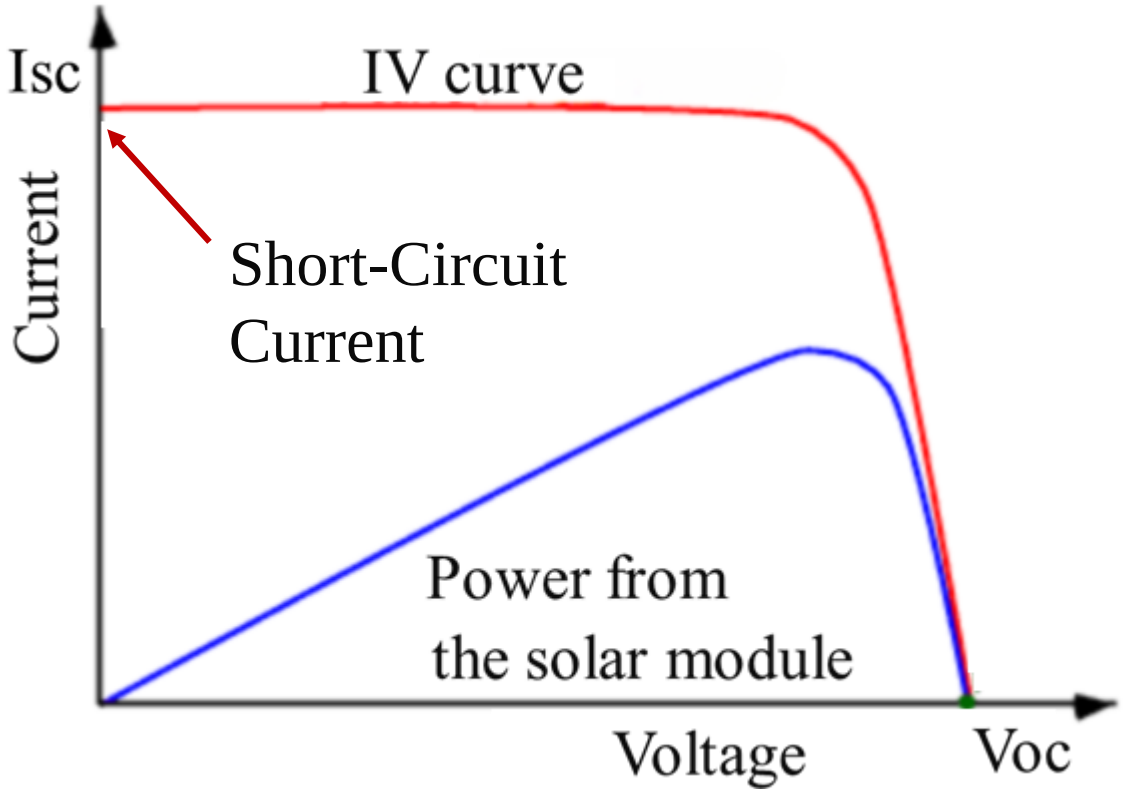
The current-voltage (I-V) characteristic curve graphically represents a solar cell's operation under specific irradiance and temperature conditions. Key parameters derived from this curve include:

- Isc
- IV curve
- Current
- Short-Circuit Current
- Power from the solar module
- Open-Circuit Voltage
- Voltage
- Voc



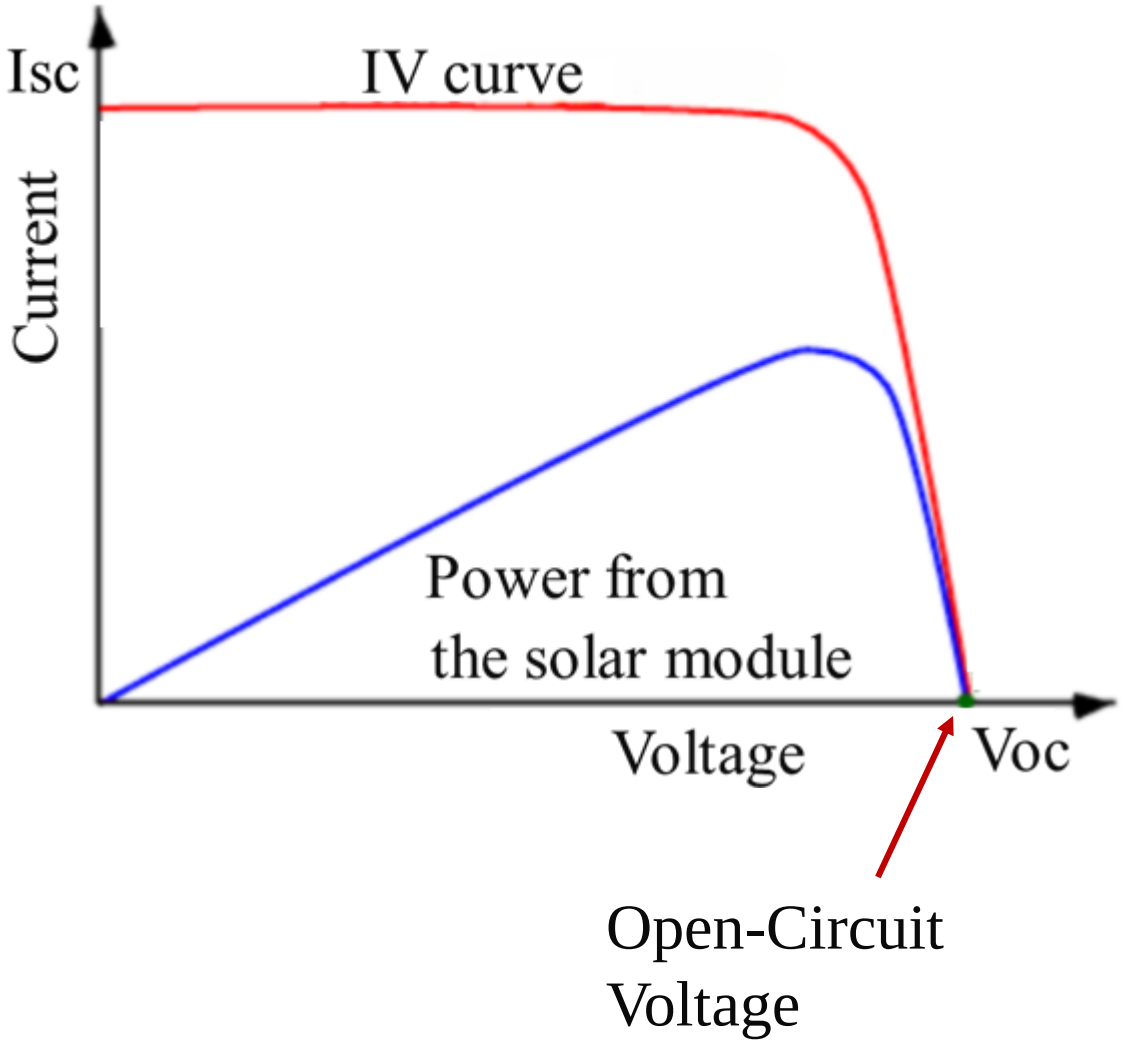
I-V characteristics of Photovoltaic devices

- **Short-Circuit Current (*Isc*):** The maximum current produced when the cell's terminals are shorted (voltage is zero). It is primarily controlled by the intensity of the solar radiation (irradiance).



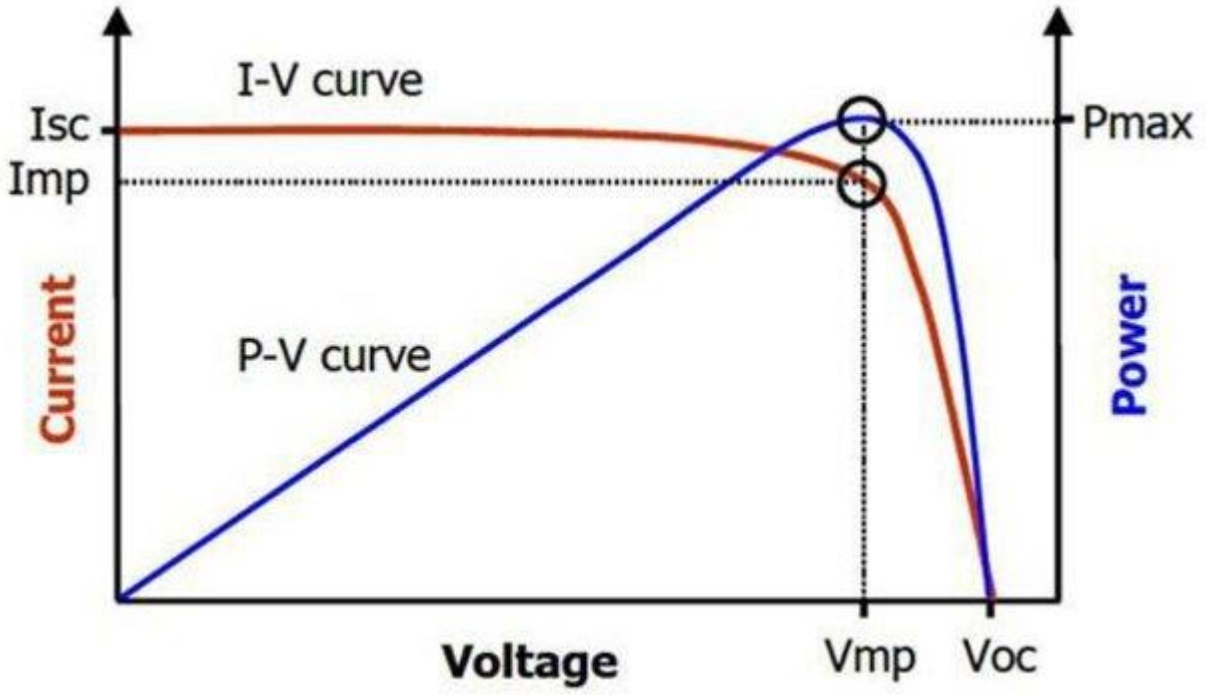
I-V characteristics of Photovoltaic devices

- **Open-Circuit Voltage (*Voc*):** The maximum voltage available when the cell is not connected to a load (current is zero). This value decreases as the cell's temperature increases.



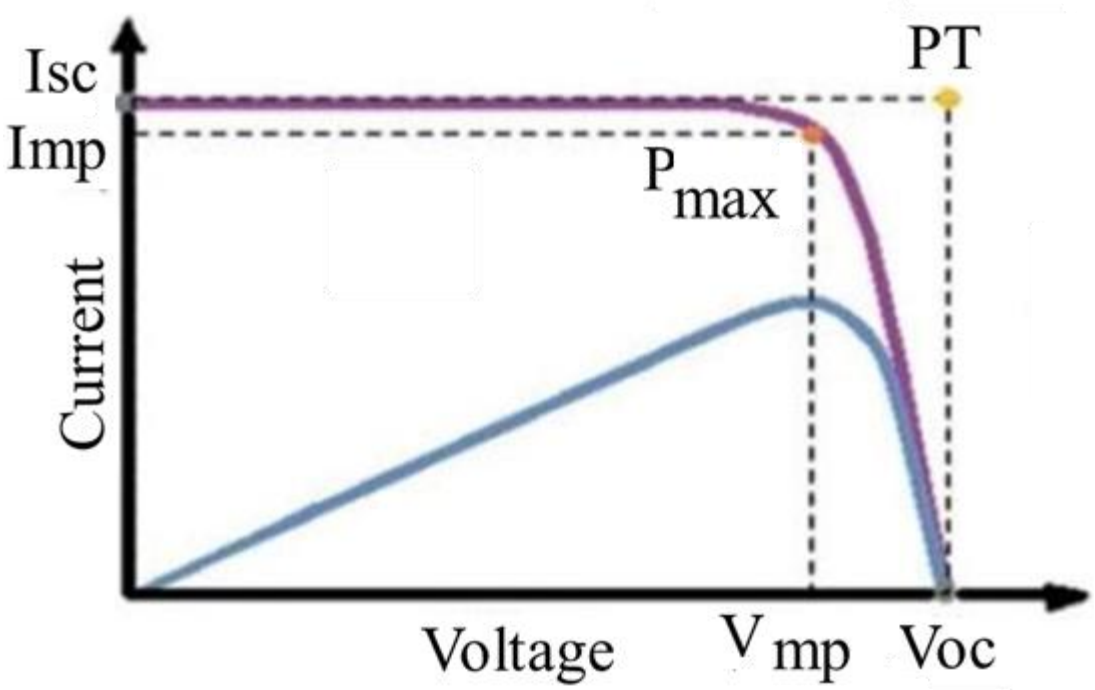
I-V characteristics of Photovoltaic devices

- **Maximum Power Point (MPP):** The unique point (***Vmp,Imp***) **on the curve where the product of voltage and current is maximized, resulting in the highest power output (*Pmax = Vmp×Imp*).**



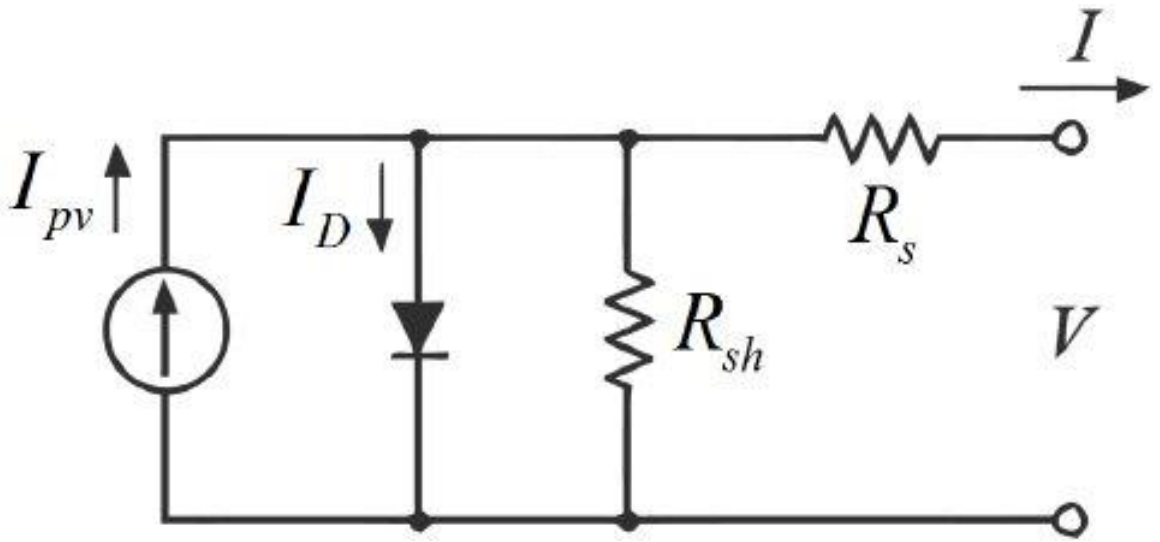
I-V characteristics of Photovoltaic devices

- **Fill Factor (FF):** A measure of the curve's "squareness" and the quality of the cell.
  - It is the ratio of maximum power to the theoretical power
  - $FF = \frac{Pmax}{Voc \times Isc} = \frac{Pmax}{PT}$
  - Higher values (typically 0.7 to 0.8) indicate a more efficient cell.



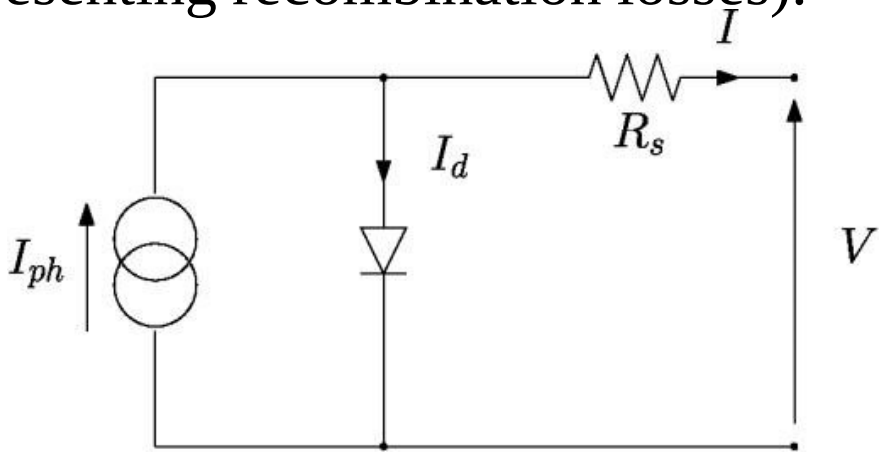
Equivalent circuits

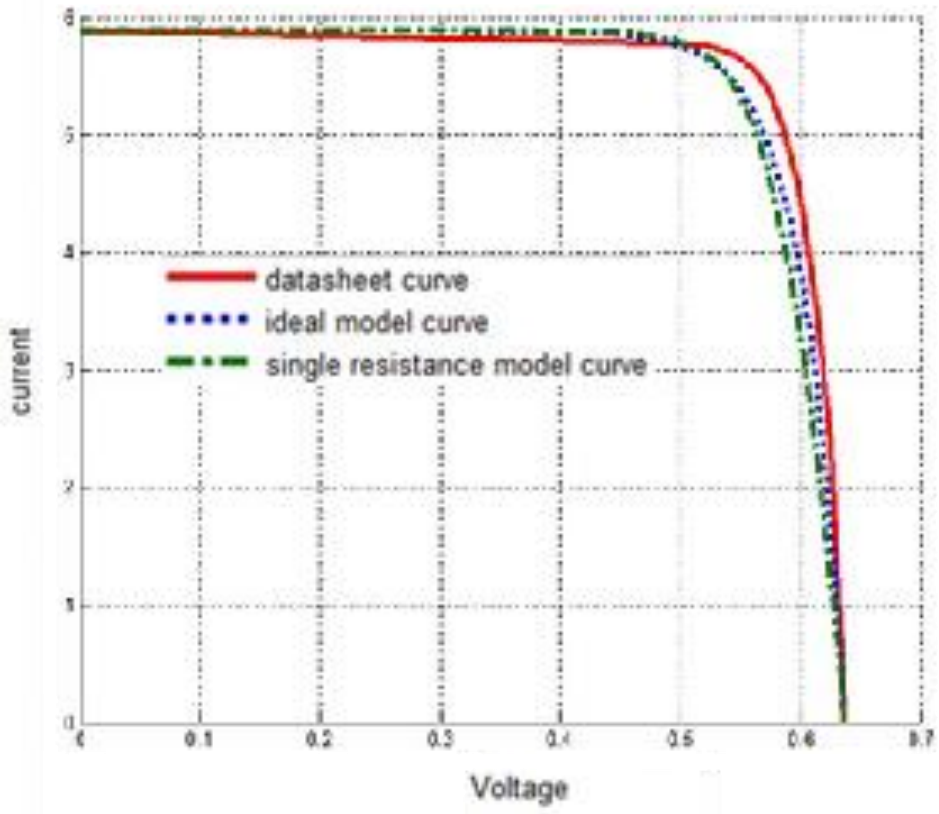
An equivalent circuit model uses standard electrical components to simulate the non-linear behavior and losses of a solar cell.



Equivalent circuits

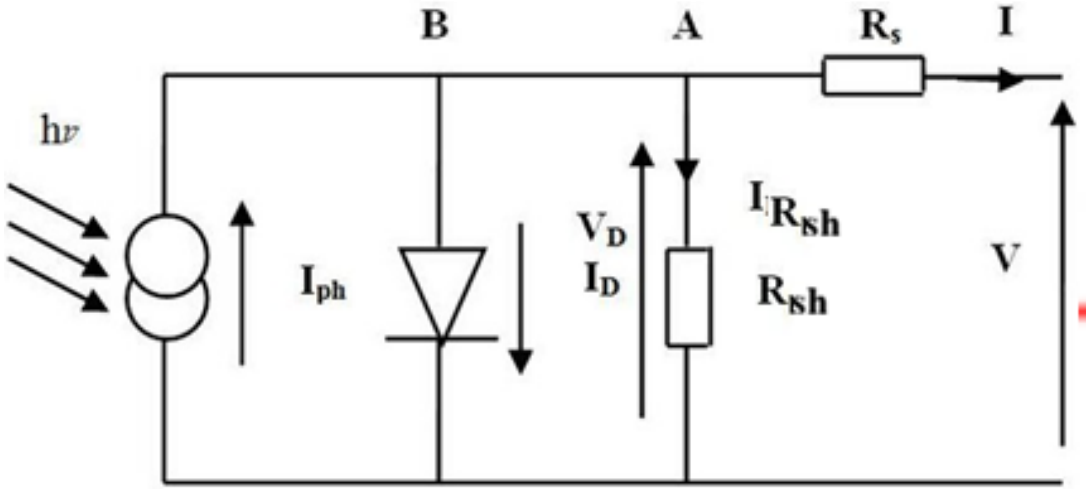
- **Ideal Model:** An ideal solar cell can be modeled simply as a **current source** (representing the photogenerated current, I_{ph} in parallel with an ideal **diode** (representing recombination losses).





Equivalent circuits

- **Real-World Model:** To accurately reflect real-world performance, two resistances are added to the ideal model:



- **Series Resistance (Rs):** Connected in series with the ideal components, it accounts for bulk resistance in the semiconductor material and contact resistance. Ideally, ***Rs*** **should be minimized to prevent power loss.**
- **Shunt Resistance (Rsh):** Connected in parallel, it accounts for current leakage paths or defects across the p-n junction. Ideally, ***Rsh*** **should be maximized to prevent current diversion.**

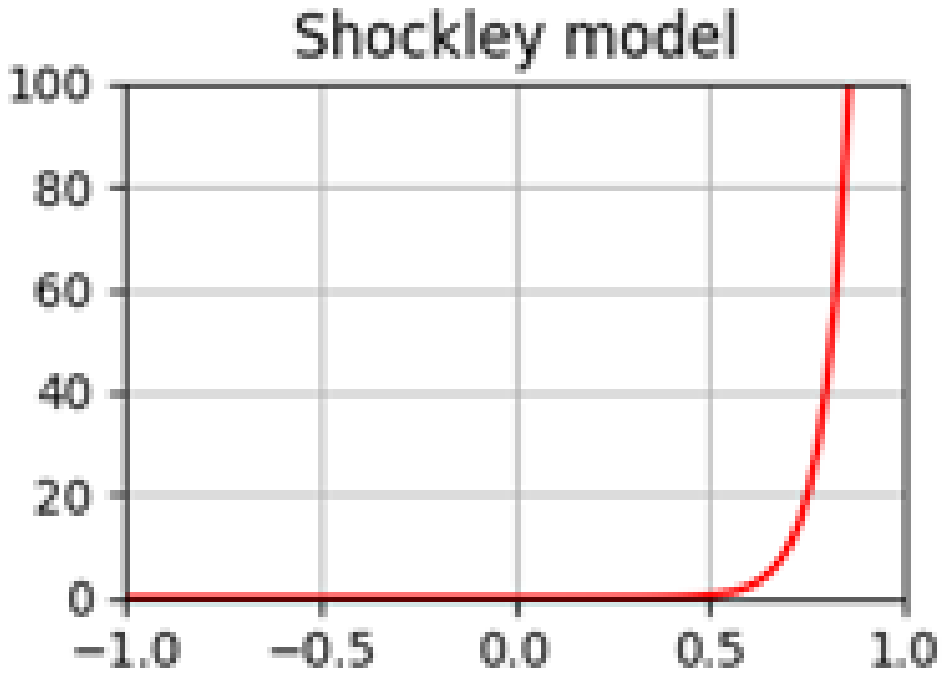
Pr. Omar EL OUTASSI
o.eloutassi@umi.ac.ma

Equivalent circuits

- Governing Equation: The output current (I) is described by a characteristic equation:

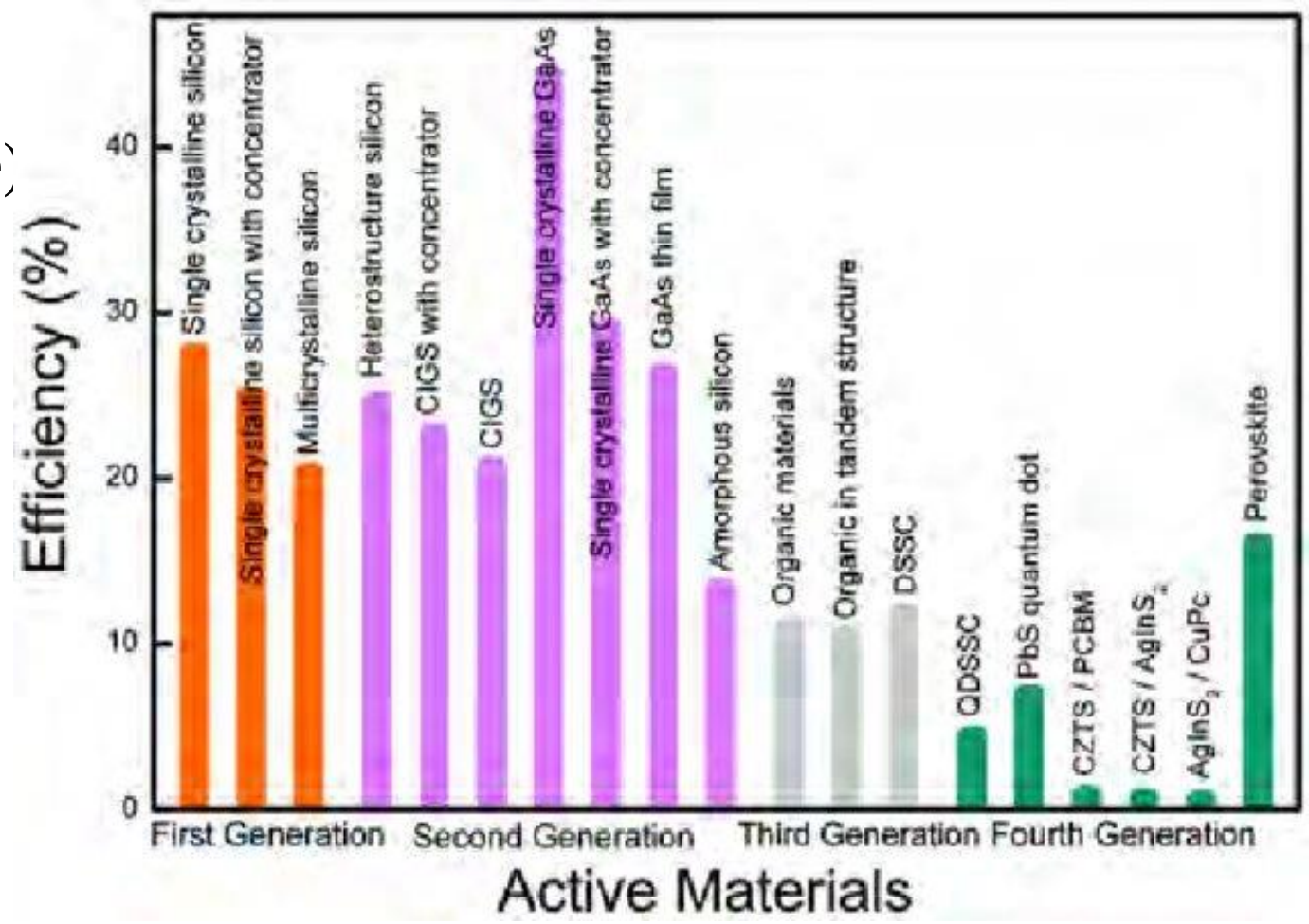
  $I = I_L - I_D - I_{Sh}$

  which can be further detailed using the Shockley diode equation and Ohm's law to describe the diode I_D and shunt I_{Sh} currents.



Efficiencies of photovoltaic devices

Efficiency is the ratio of the electrical power output of a solar cell (or module) to the amount of solar power (irradiance) hitting it, expressed as a percentage.



Pr. Omar EL OUTASSI
o.eloutassi@umi.ac.ma

Efficiencies of photovoltaic devices

- **Cell vs. Module Efficiency:** Cell efficiency is always higher than module efficiency because modules include inactive space between cells and wiring. Commercial modules typically operate around 15-20% efficiency.
- **Measurement Standards:** Efficiency is measured under Standard Test Conditions (STC): 1000 W/m² irradiance, 25°C cell temperature, and air mass 1.5.

#	Solar Panel Type	Efficiency	Efficiency %
1.	Monocrystalline	High	15% – 22%
2.	Polycrystalline	Lesser	12% – %18%
3.	Thin-Film	Versatile	10% – 12%
4.	Bifacial (PERC)	Higher	15% – 25%
5.	CdTe	Moderate	9% – 11%

Efficiencies of photovoltaic devices

- **Limiting Factors & Losses:**
  - **Material Limitations:** The intrinsic band gap of the material limits the range of the solar spectrum a single cell can absorb; photons with energy below the band gap are not absorbed, while excess energy from high-energy photons is lost as heat.
  - **Temperature:** Higher temperatures actually decrease a solar cell's voltage output and efficiency.
  - **External Factors:** Shading, dust accumulation (soiling), and the angle of the sun all reduce the amount of light reaching the cell, lowering performance.

End chapter 4

Video
https://www.youtube.com/watch?v=Yxt72aDjFgY