Sustainable Solar Energy Technologies & Job Opportunities

Section 3 & 4

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Contents

3. Solar to electric technologies, Components selection, tandem structures, design of solar panels, micro and nano device processes, advanced PV system design, novel heterojunction solar cell structures, organic solar cells, Perovskites solar cells, advanced Thermophotovoltaics, vehicular solar technology module (car, aircraft, satellites), solar farmss

4. Solar cells and life cycle analysis: Energy conversion limitations, I-V characteristics, fill factors, maximum power point, IPCE analysis, cell efficiency, losses, effect of radiation, temperature, sunshine recorder, solar angle, solar simulators, solar panel installation – geometry, parameters, Solar power plants, building infra-PV installation, operation costs, Degradation analysis, AI and Machine learning, MATLAB tools in solar technologies.

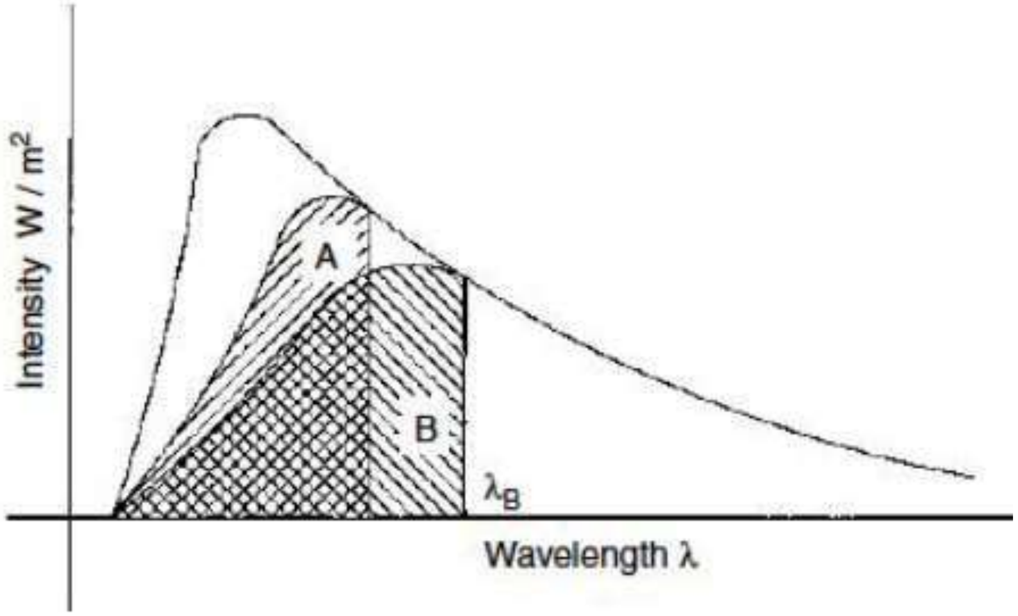
Case studies: Modelling of solar energy conversion, Solar farms, Rooftop solar panel, solar for automobiles, Hybrid PV systems, Economic and efficiency analysis.

Tandem solar cells

- Efficiency can be improved using multi layer cells (tandem devices), with high bandgap material at top and low bandgap material below

(low frequency or longer wavelength radiation penetrates better).

- Wider spectral absorption
- Modulation of charge carrier separation
- The open circuit voltage of the stack is the sum of the open circuit
- voltages of the individual cells.

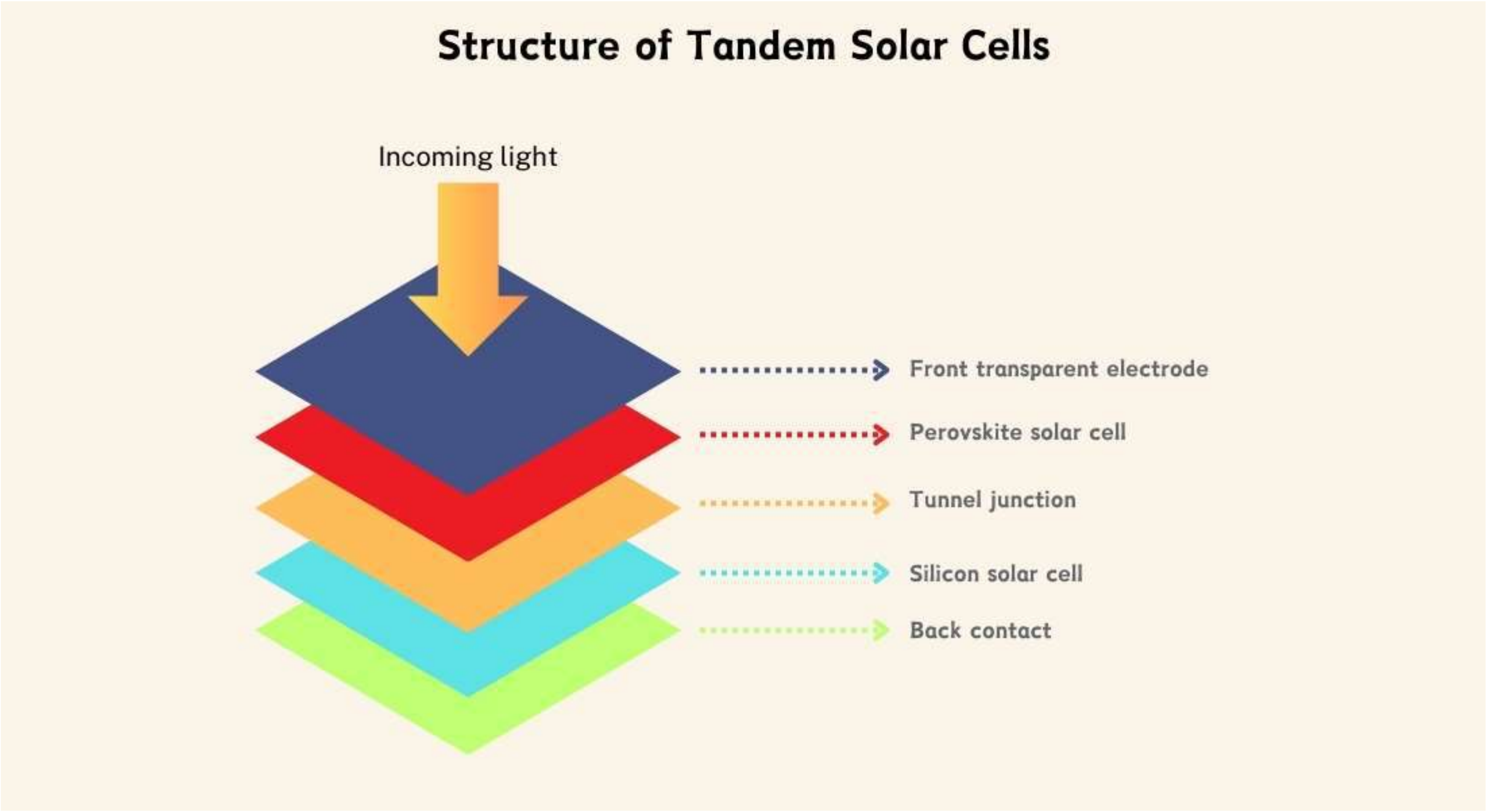


Part of the spectrum captured by a two layered tandem cell

Tandem solar cells

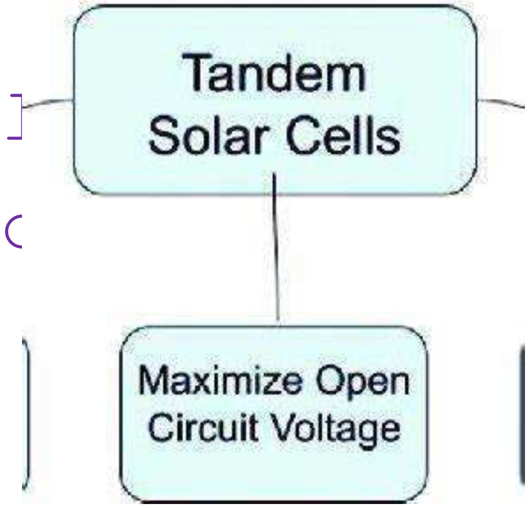
Components

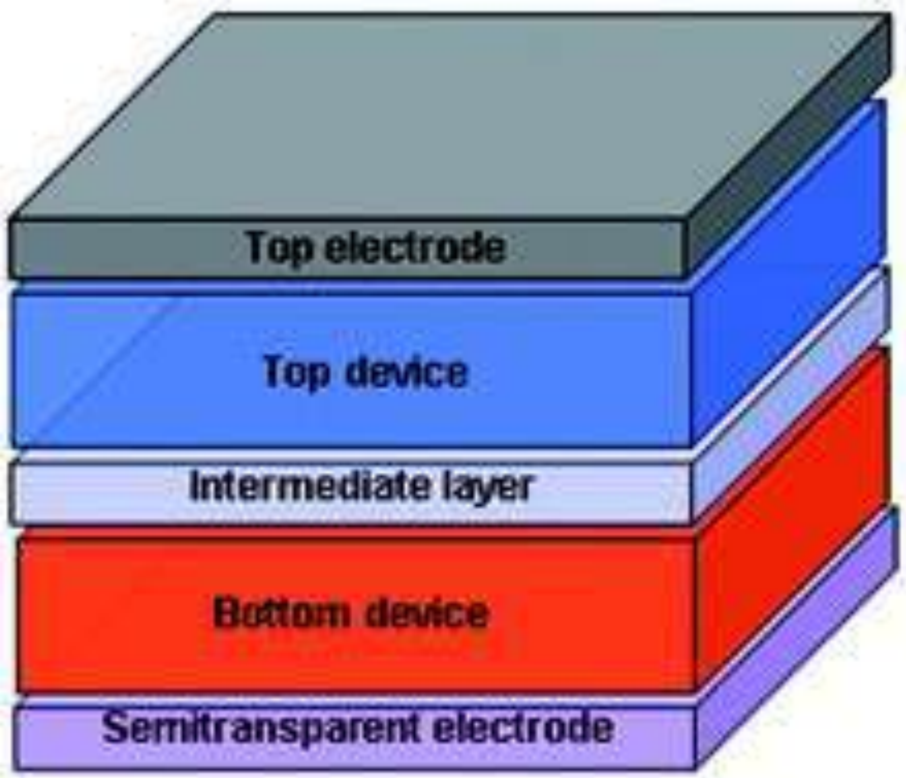
Transparent elec
Metal contacts
Cell 1 (high Eg)
Tunnel junction
Cell 2 (low Eg)
Metal back conta

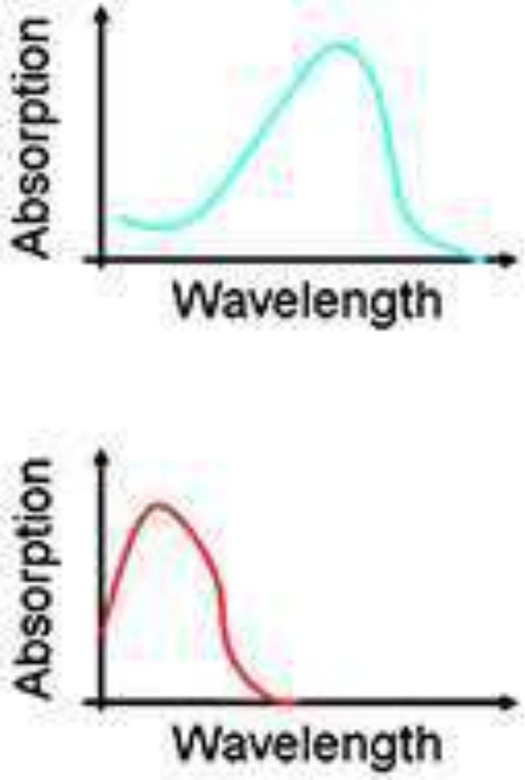


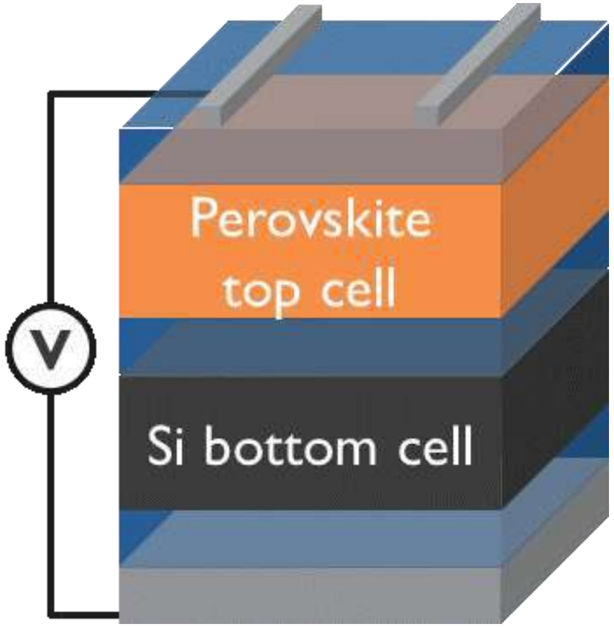
Tandem solar cell

- With silicon cell and perovskite cel
- Maximize wider wavelength light absc
- Increase the open circuit voltage -



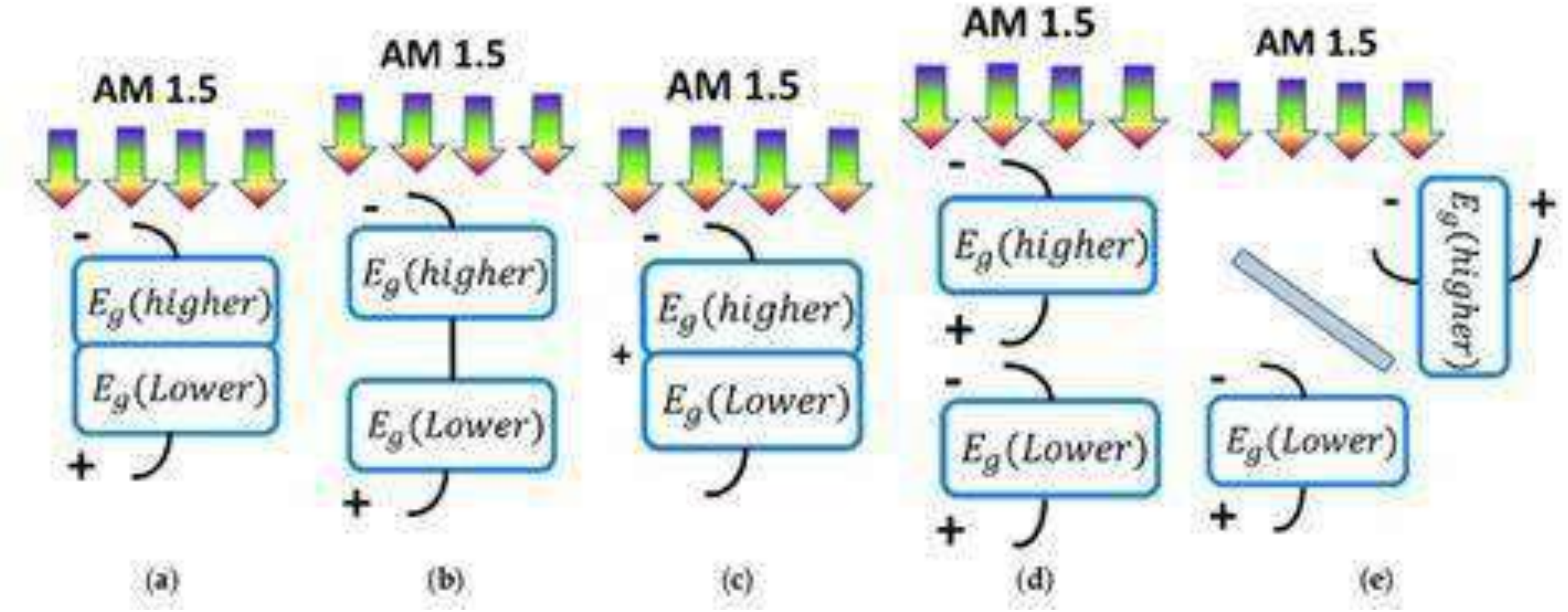






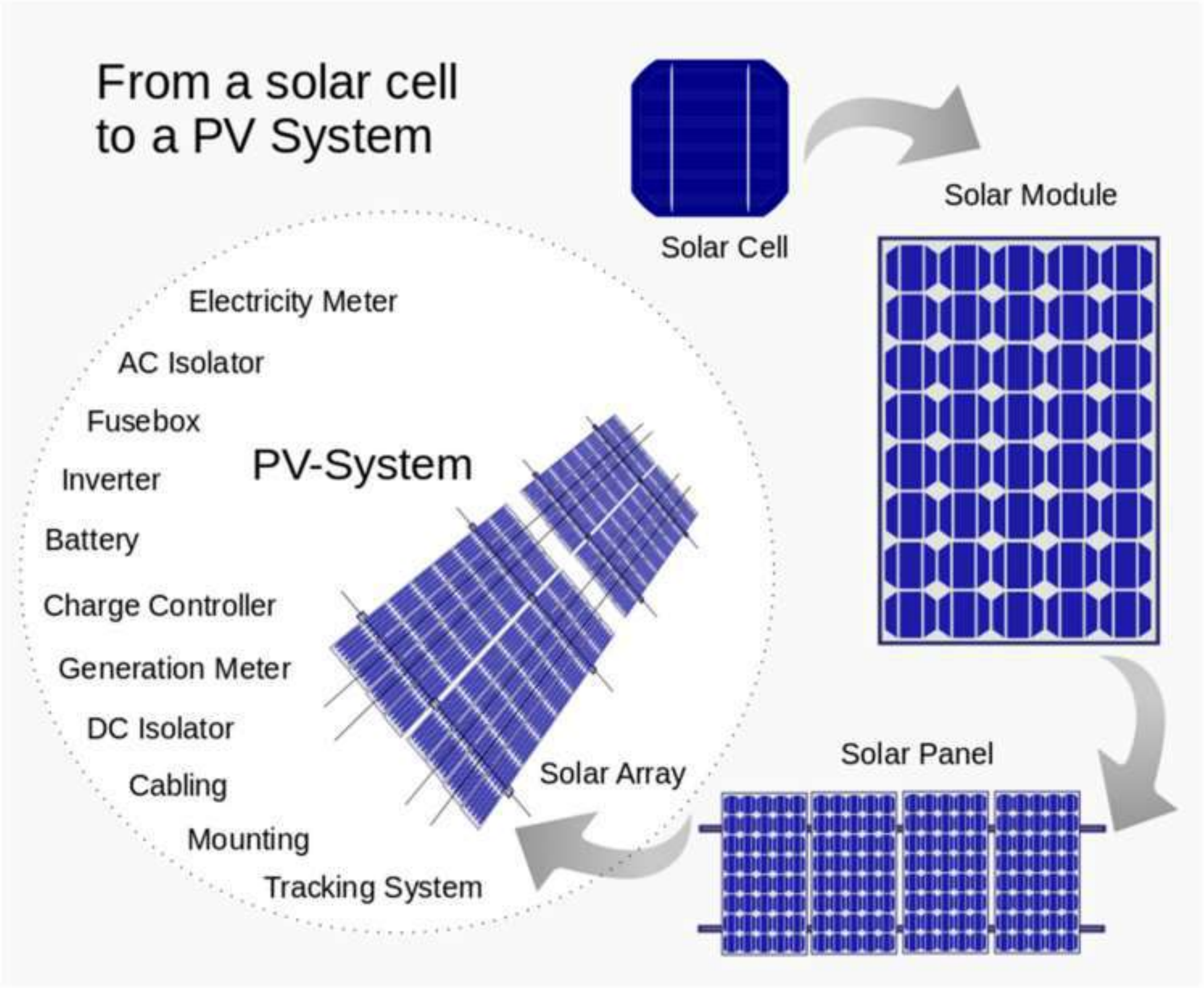
Solar Energy opportunities

- Higher band gap and lower band cell with various configuration
- Increase the open circuit voltage
- Increase the photon to conversion efficiency

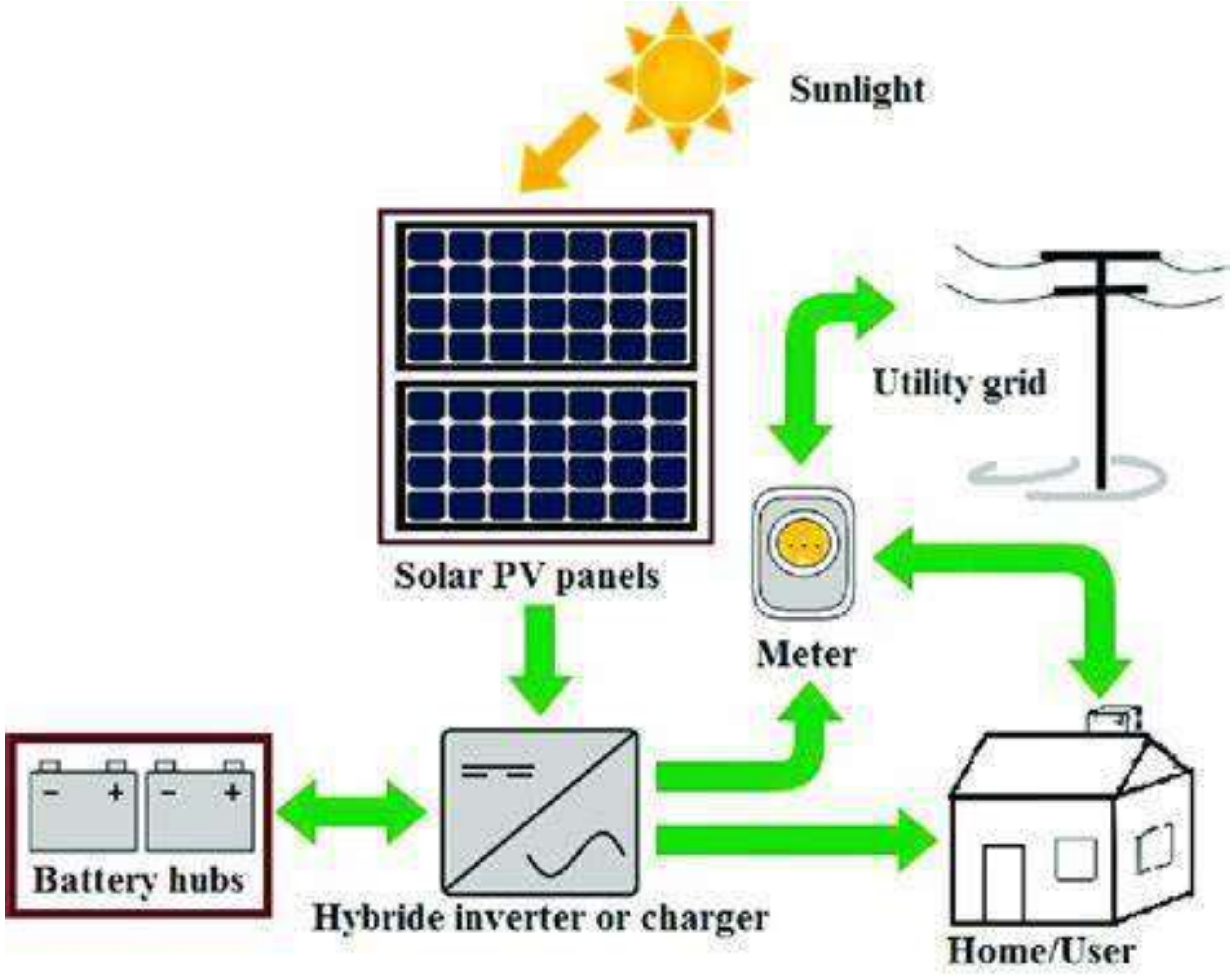


PV design

- Array of solar cells
- Charge controller
- Inverters
- Battery and Grid integration
- Mounting and mobility
- Tracking system



PV design and installation

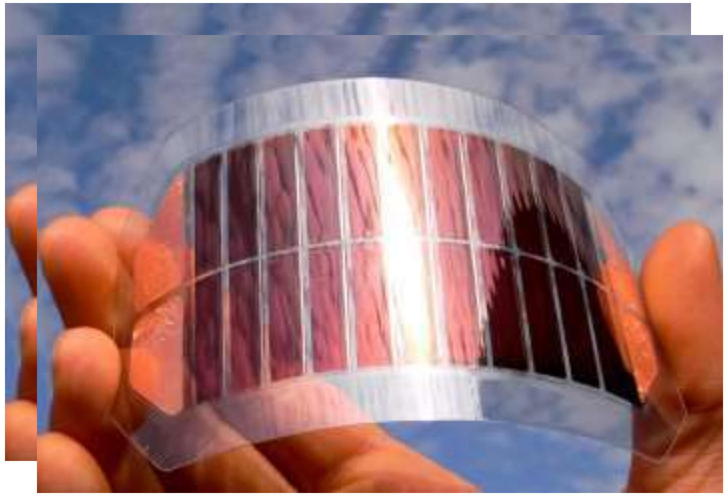


Flexible solar cells - organic

- Flexible organic solar cells easy to fabricate
- Lower efficiency
- Higher recombination due to

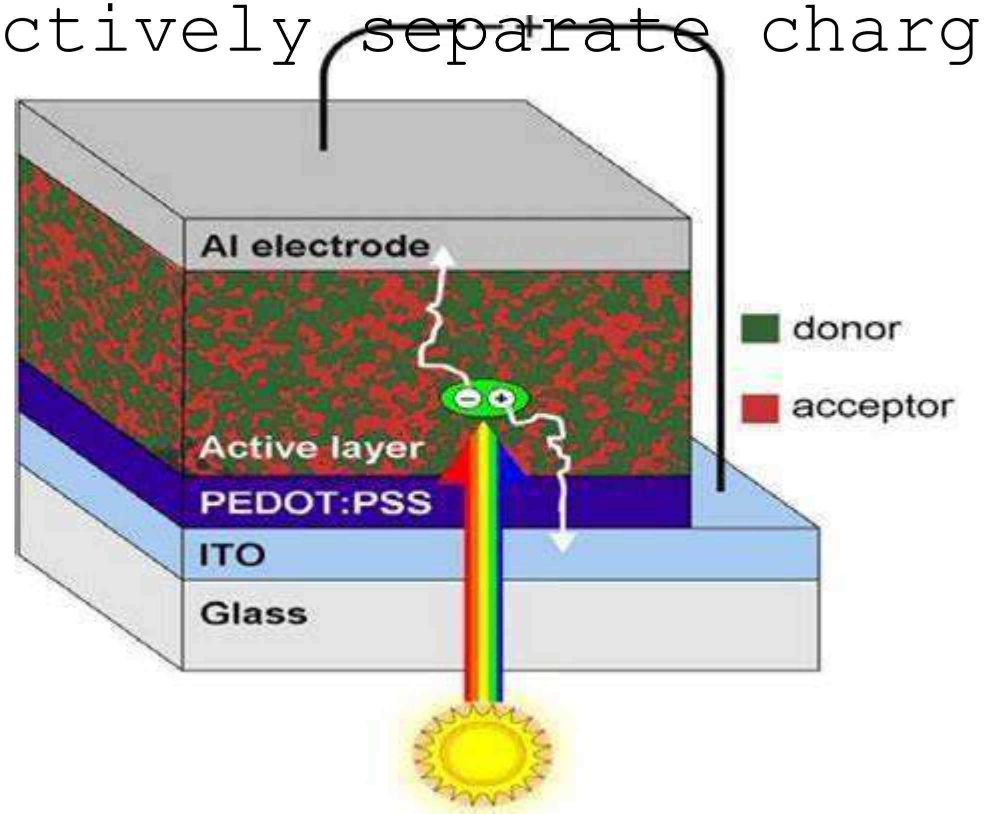
Poor ordering or crystallinit

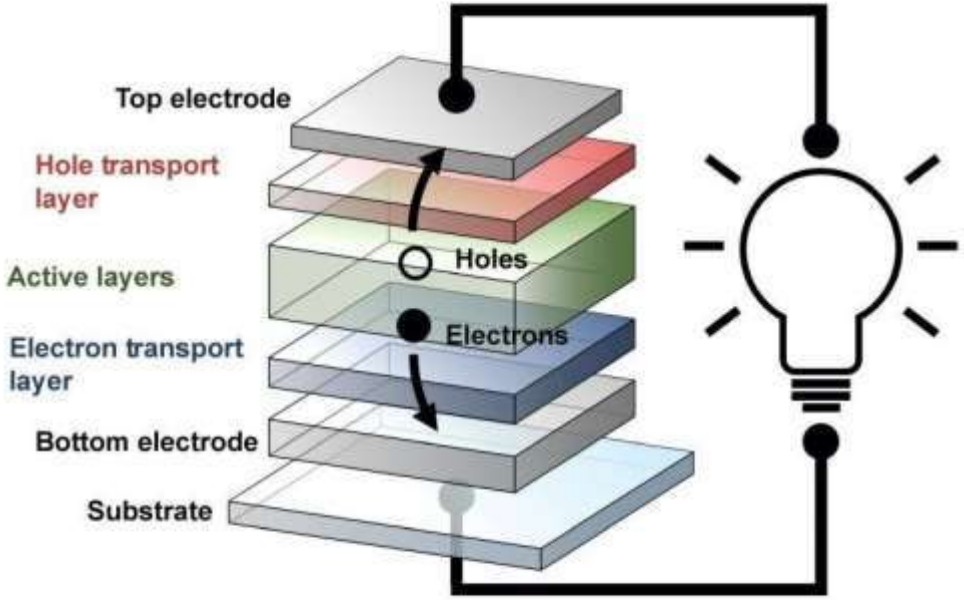
Low efficiency



Organic solar cells

- Active layers can be with donor – acceptor type organic molecules and polymers
- Hole transport or electron trans layers selectively separate charges

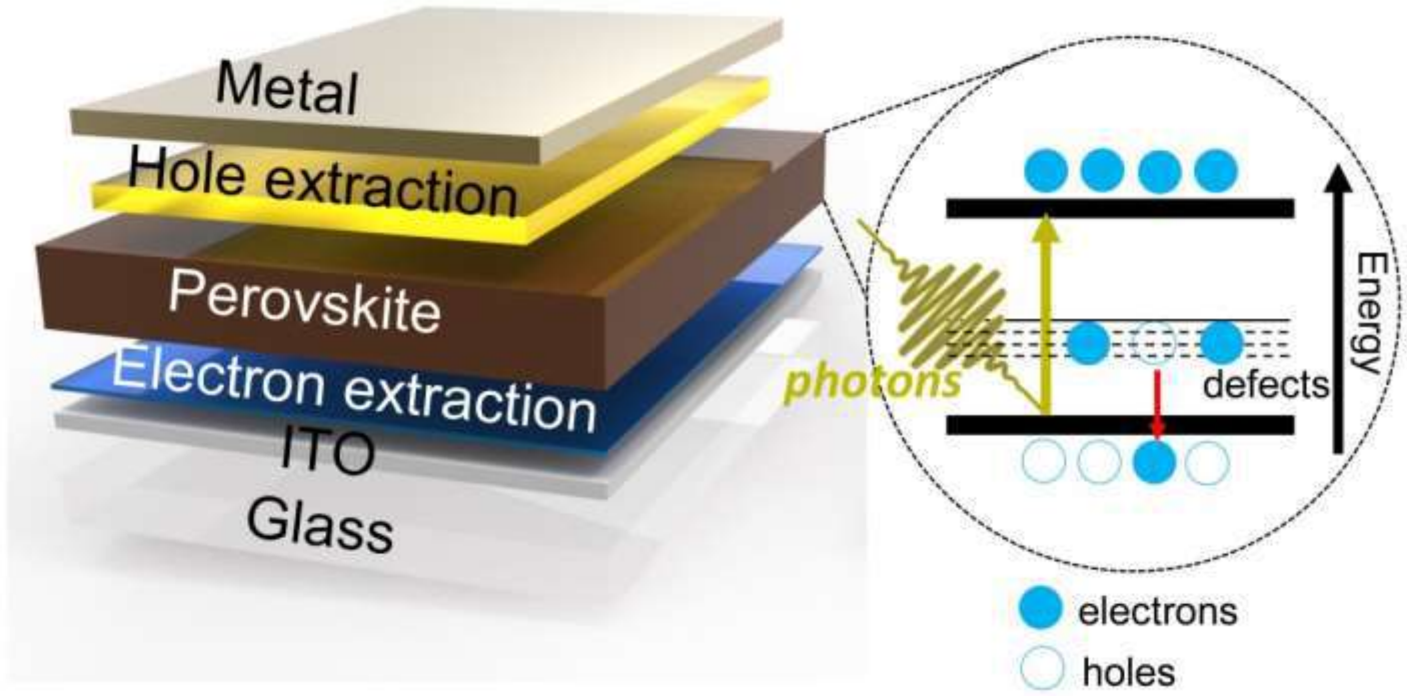




Perovskite solar cells

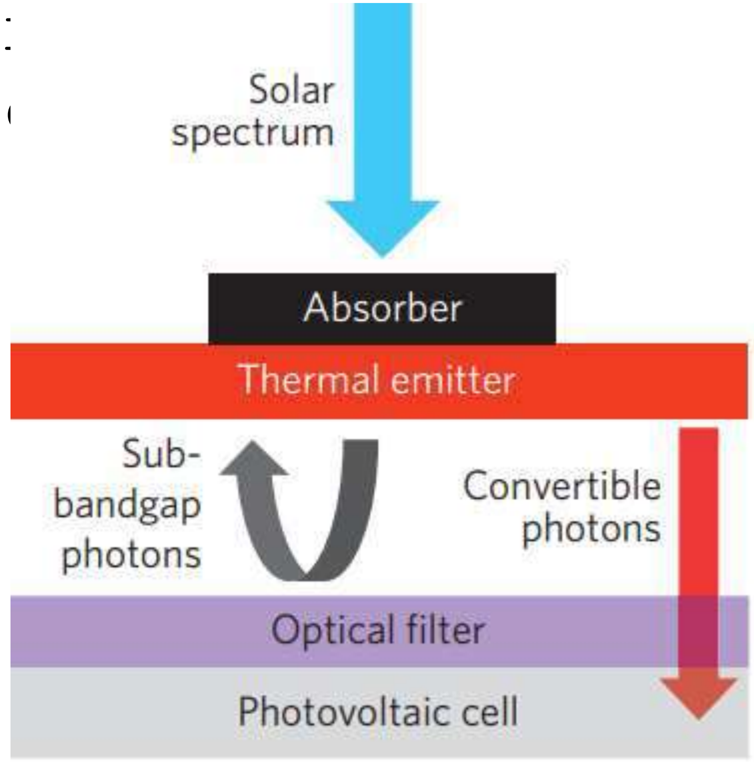
1. Absorption

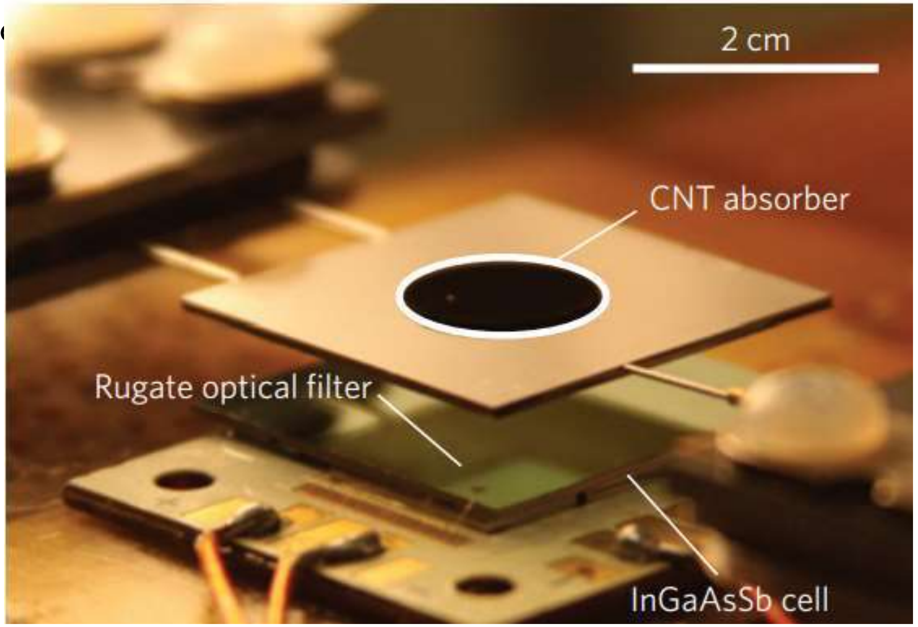
- When light is absorbed by a material, its energy is transferred to the atoms, molecules, or electrons in the material.



Thermo-photovoltaics

- Incident light – thermal based spectral shaping – Absorber
- Broadband solar radiation to narrow band thermal radiation
- To e[...] ol[...] effi[...]





Solar powered locomotives

- Low power efficiency
- Light irradiation limitations at surface of earth
- Advantages with satellite solar power
- At higher atmosphere, altitudes solar power is 10 times intense than on the down surface

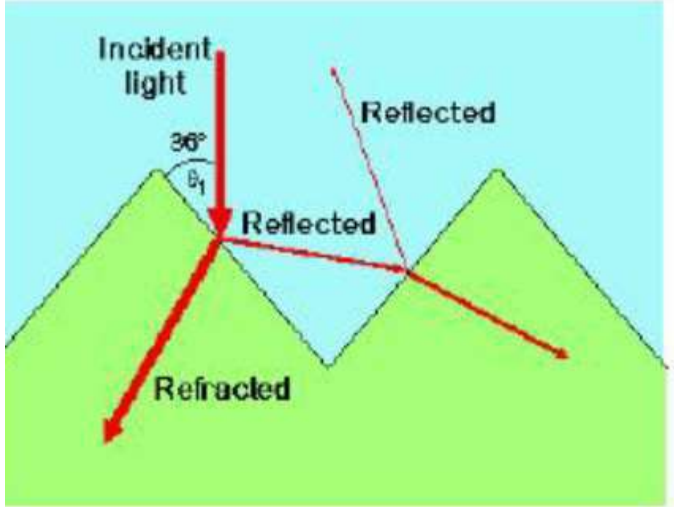
Section 4 – Characterization of Solar cells

Solar cell characterisation

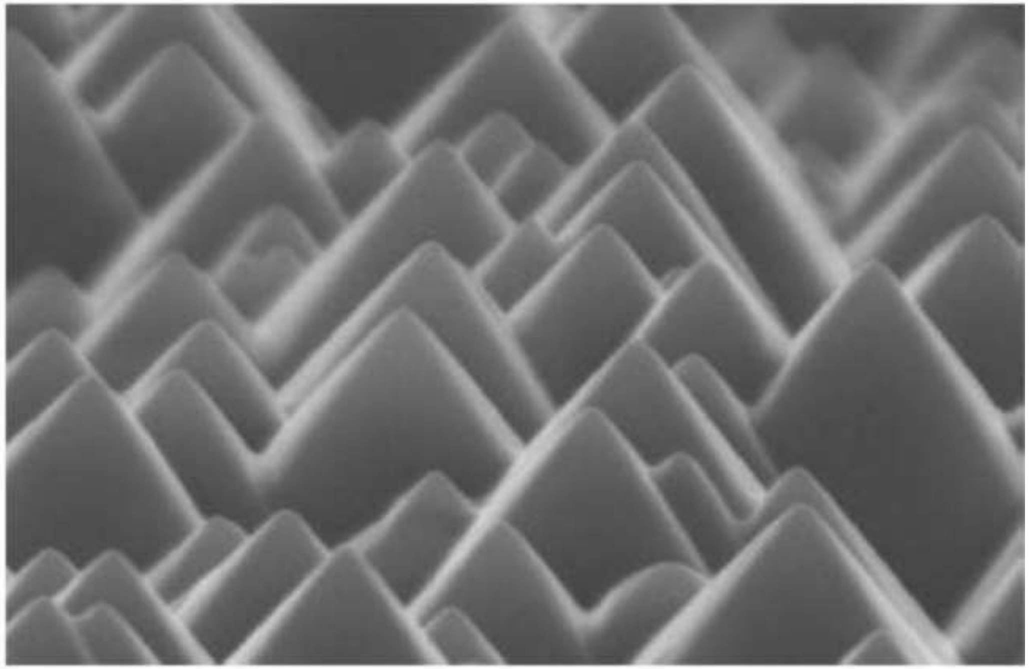
. Textured, micro and nanostructured surfaces increases the light absorption.

Increasing Absorption

Effect of Textured Surfaces on Light Absorption



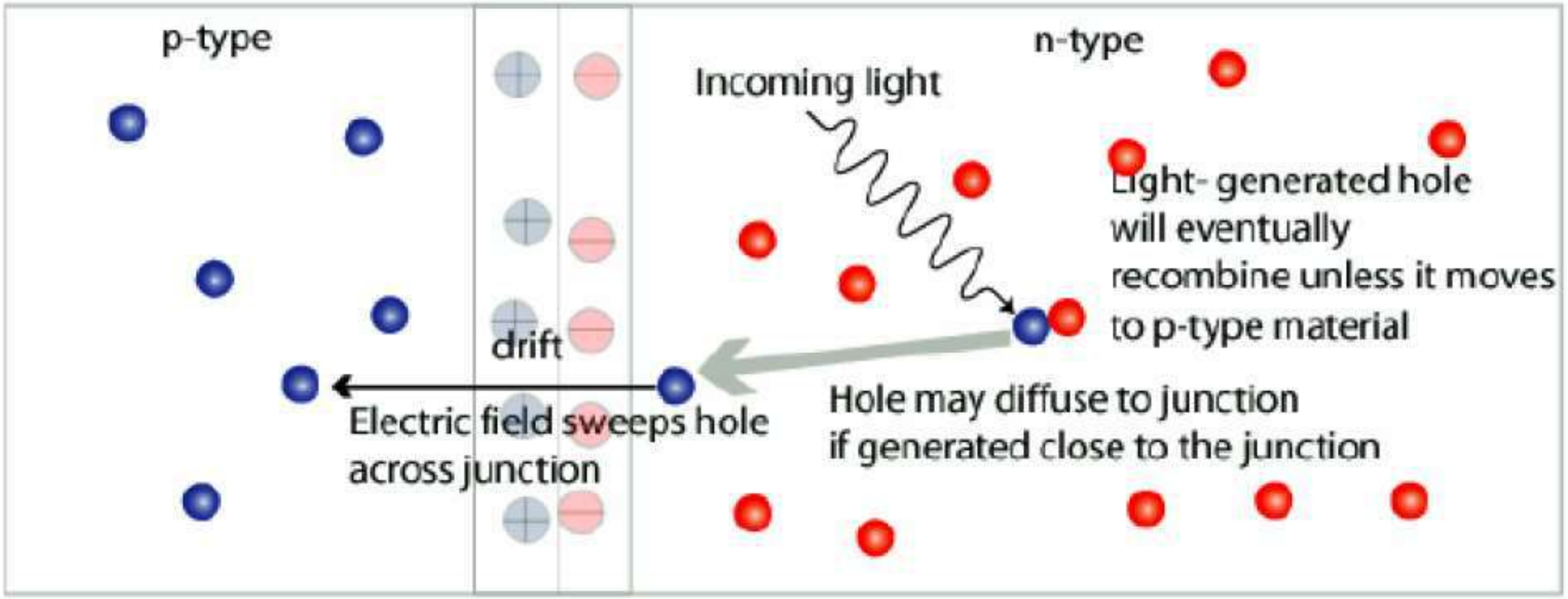
SEM image of textured silicon



Solar cell characterisation

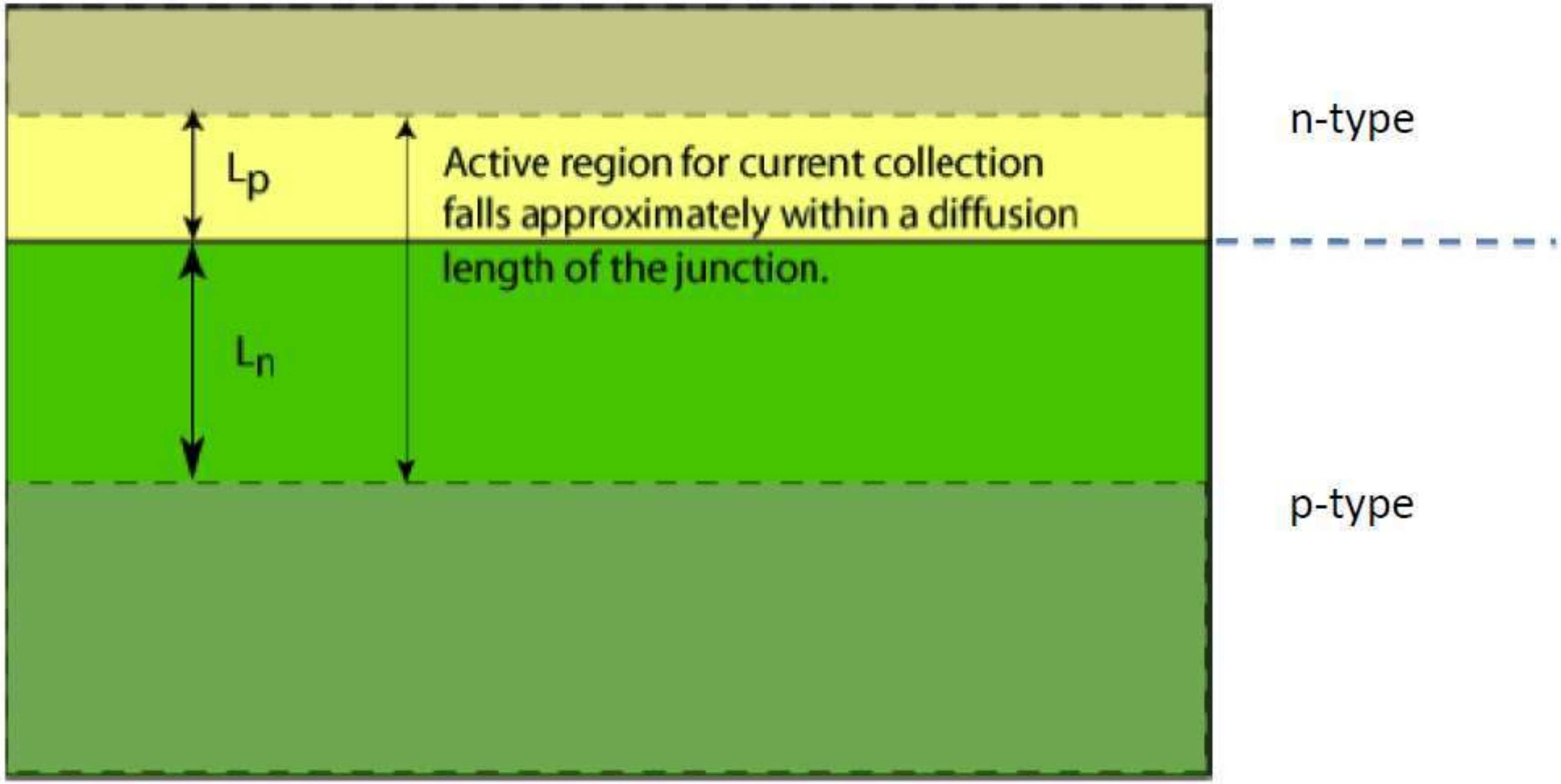
Collection Probability

- A light generated minority carrier can readily recombine.
- If it the carrier reaches the edge of the depletion region, it is swept across the junction and becomes a majority carrier. This process is collection of the light generated carriers.
- Once a carrier is collected, it is very unlikely to recombine.



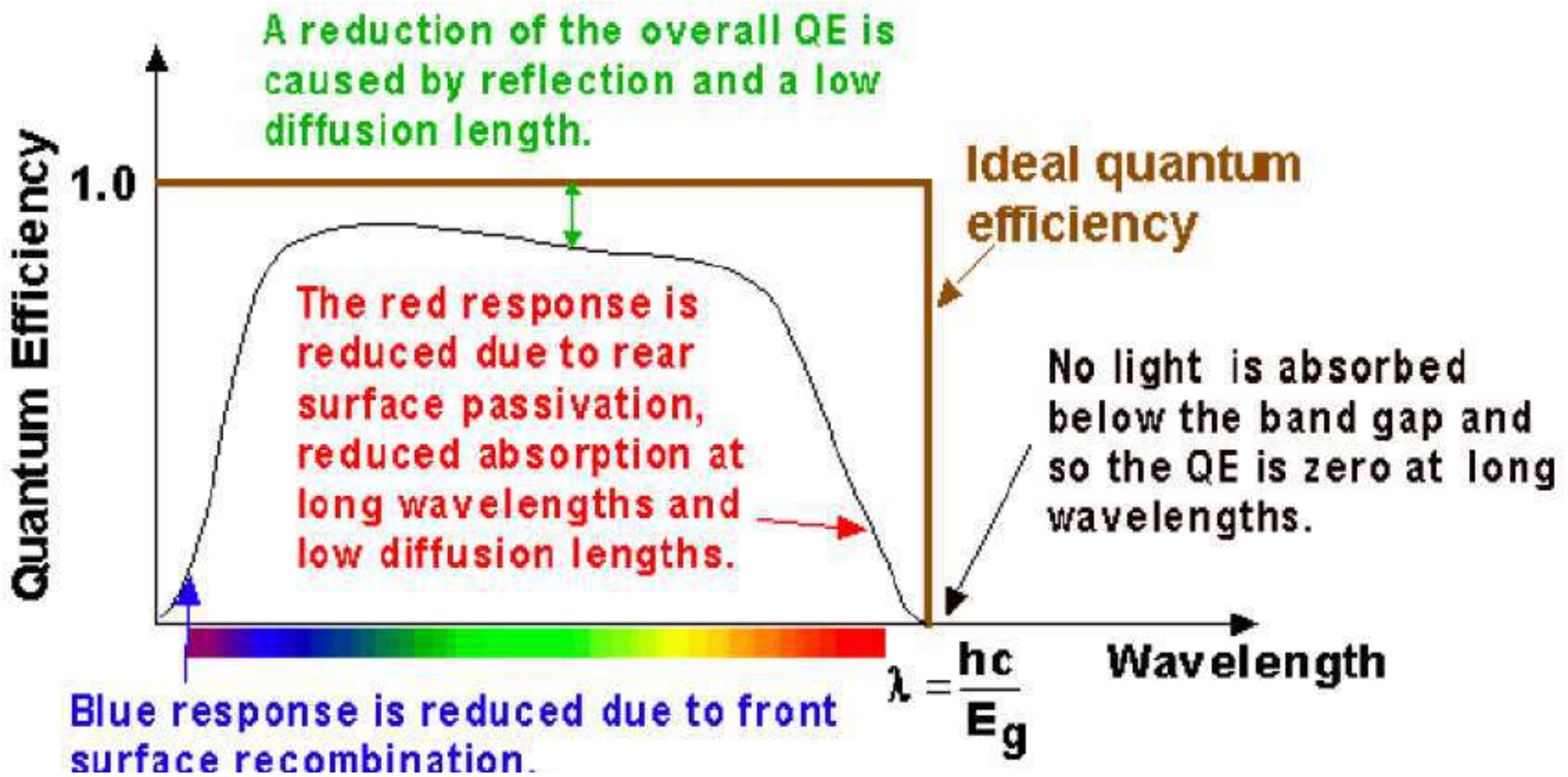
Solar cell characterisation

Collection Probability



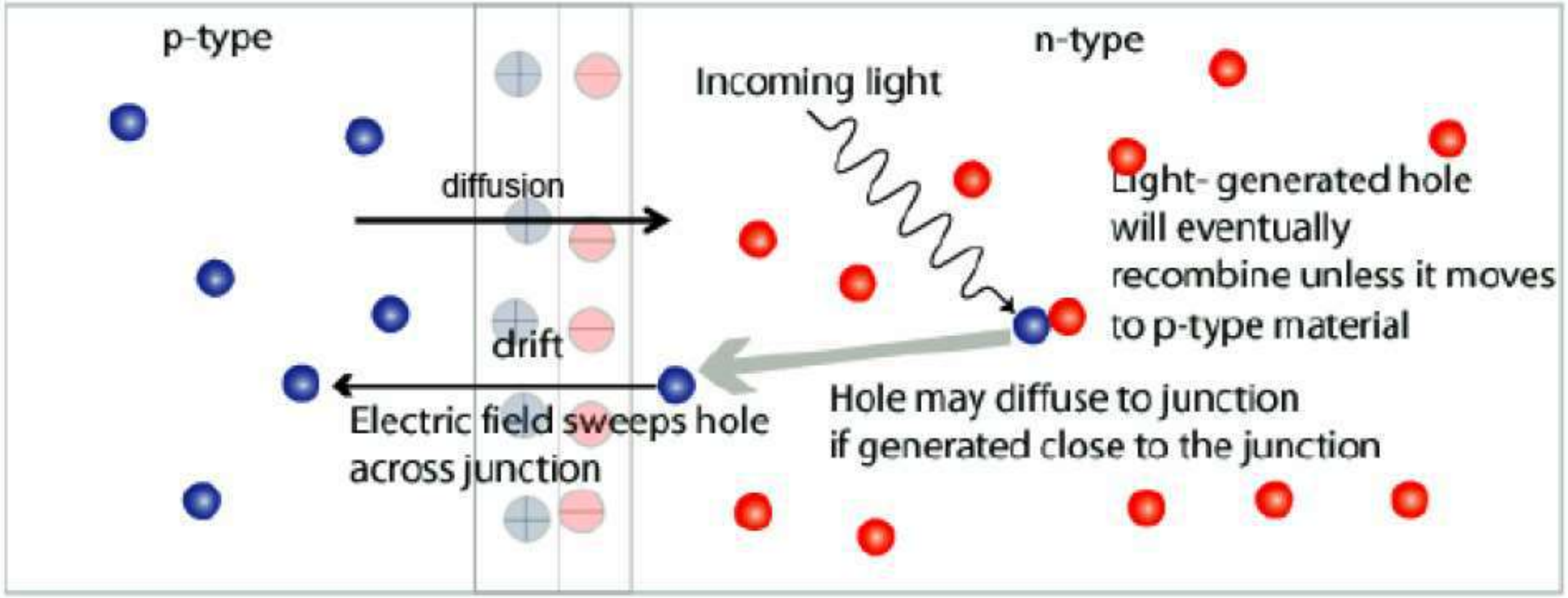
Collection probability is low further than a diffusion length away from junction

Solar cell characterization – spectral response - efficiency



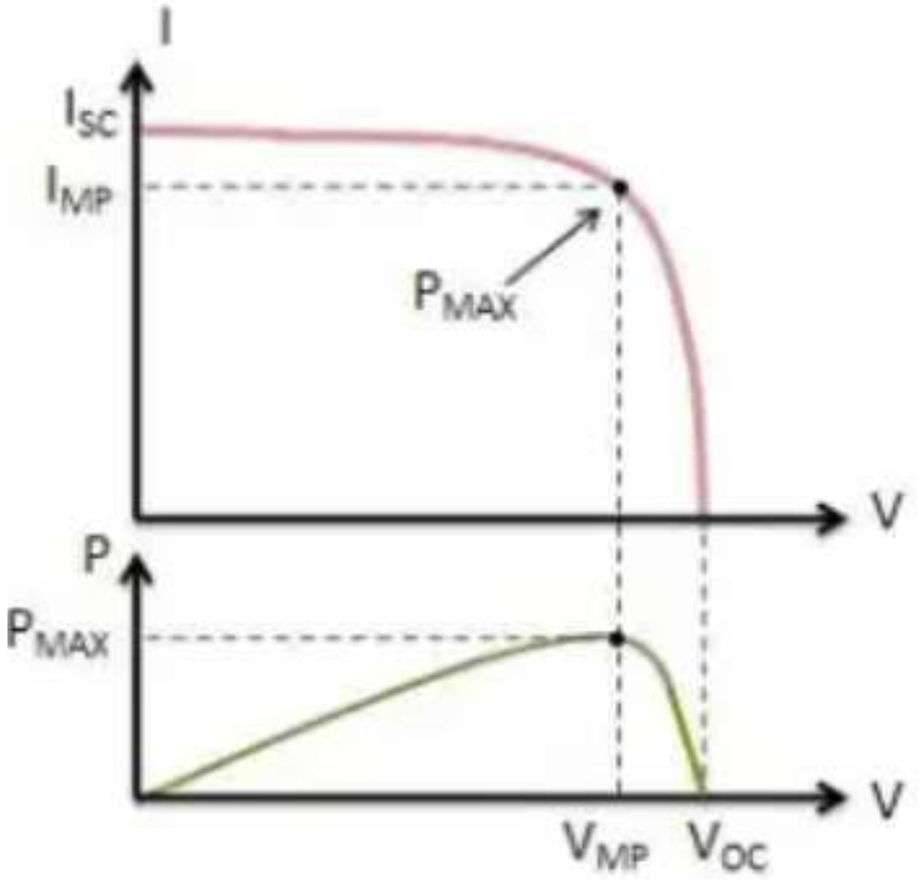
Solar cell characterization – Effect on open circuit voltage

- If collected light-generated carriers are not extracted from the solar cell but instead remain, then a charge separation exists.
- The charge separation reduces the electric field in the depletion region, reduces the barrier to diffusion current, and causes a diffusion current to flow.



Solar cell characterisation

- . **Short Circuit Current**: This is the highest current a solar cell can provide under optimal conditions without being damaged.
- **Open Circuit Voltage**: The voltage across the solar cell's terminals when there is no load connected, typically around 0.5 to 0.6 volts.
- **Efficiency**: The efficiency of a solar cell is the ratio of its maximum electrical power output to the input solar radiation power, indicating how well it converts light to electricity



Solar cell characterisation

- . **Short Circuit Current**: This is the highest current a solar cell can provide under optimal conditions without being damaged.
- It is measured by short-circuiting the cell's terminals under optimal conditions. These conditions include the intensity of light and the angle of light incidence.
- Since current production also depends on the exposed surface area, it is better to express this as maximum current density, which is the ratio of short circuit current to the cell's exposed surface area

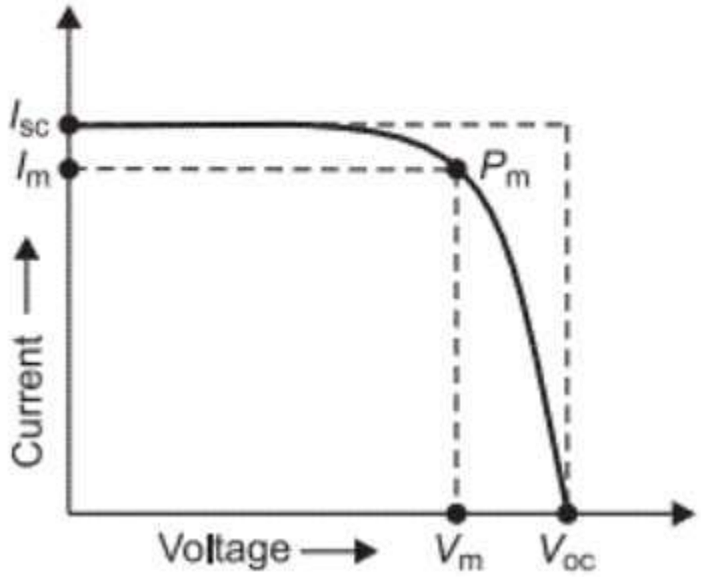
$$J_{sc} = \frac{I_{sc}}{A}$$

Solar cell characterisation

- **Maximum Power Point of Solar Cell**

- The maximum electrical power one solar cell can deliver at its standard test condition. If we draw the v-i characteristics of a solar cell maximum power will occur at the bend point of the characteristic curve.

- It is shown in the v-i characteristics of solar cell by P_m



Solar cell characterisation

- **Fill Factor of Solar Cell**
- The ratio between product of current and voltage at maximum power point to the product of short circuit current and open circuit voltage of the solar cell

$$Fill\ Factor = \frac{P_m}{I_{sc} \times V_{oc}}$$

- **Efficiency of Solar Cell**
- This is defined as the ratio of the maximum electrical power output to the input radiation power, expressed as a percentage.
- On Earth, the radiation power is about 1000 watts per square meter. If the cell's exposed surface area is A, the total radiation power on the cell will be 1000 A watts

$$Efficiency(\eta) = \frac{P_m}{P_{in}} \approx \frac{P_m}{1000A}$$

Solar angle - PV

- The angle between a photovoltaic (PV) panel and the sun affects the efficiency of the panel.
- **Elevation Angle:** Measures the Sun's height above the horizon (ranges -90° to 90°)
- **Azimuth Angle:** Measures the Sun's position clockwise from North (ranges 0° to 360°).
- **Solar Tilt:** The angle between a

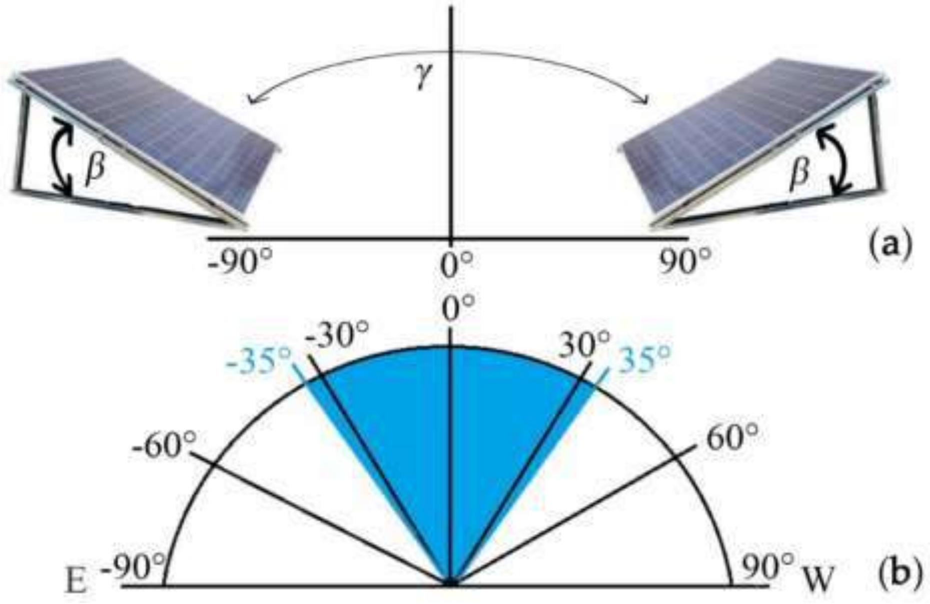
photovoltaic (PV) panel and

the Sun affects panel efficiency

Solar Tracking Systems: Improve PV

panel efficiency by following the Sun's

Movement (AI tools – movement of panels)



Solar Simulator

- A solar simulator is simply a light source that has specific quantifiable similarities to natural sunlight, namely in its spectral distribution and intensity
- The purpose of a solar simulator is to provide a consistent, controllable source of illumination in a laboratory environment.
- It can be used for testing any materials or processes that are photosensitive. This may be relevant for many different applications in a wide range of field
- Performance testing of solar cells/modules, New energy development (e.g., water splitting), photocatalysis, water treatment, testing plants, photosynthesis, biotech, cosmetics, medicine, bioluminescence

Solar Simulator for irradiance

- Solar radiation that arrives on the surface of the earth is modified by the atmosphere and environment on and around the earth

Direct: radiation that passes directly from the sun to the earth’s surface without changing direction.

Diffuse: radiation that has been scattered by gas, particles, etc. in the atmosphere, modifying its direction before reaching the target.

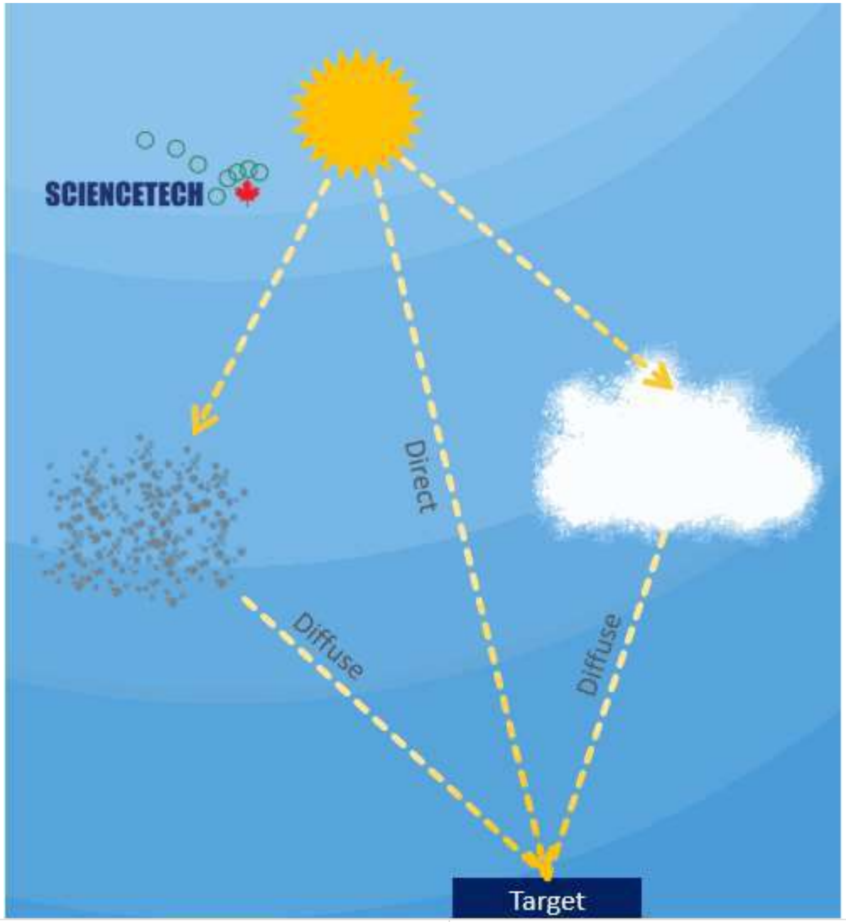
- **Global:** direct and diffuse radiation considered together at a target plane

Solar Simulator for irradiance

The effects of direct and diffuse radiation on a target are indicated using the labels AM1.5D and AM1.5G:

AM1.5D: The direct radiation arriving at the target plane when sunlight passes in an unimpeded line through 1.5 times the minimum thickness of the atmosphere.

- **AM1.5G:** The direct and diffuse radiation arriving at the target plane, including radiation passing unimpeded from the sun and also diffused or reflected by gas, particles, surfaces, etc. in the surrounding environment.
- In photovoltaic and solar cell current-voltage testing, AM1.5G is the standard solar spectrum and is most commonly used.



	Irradiance (W/m^2)
AM0	1367 W/m^2
AM1.5D	900 W/m^2
AM1.5G	1000 W/m^2

Solar farms and installations

- A solar farm is generally a large-scale solar installation. Solar farms are most often community solar projects or utility-scale solar power plants.
- Solar farms usually have hundreds to thousands of solar modules installed in a large field.
- Solar farms send solar energy to electricity grids, which, in turn, lessens their reliance on power produced by fossil fuels.

UTILITY-SCALE SOLAR FARMS	COMMUNITY SOLAR FARMS
Sell electricity directly to utilities	Sell electricity to customers
A large operation for increased energy production	Smaller in size compared to utility-scale farms
Power produced here is either owned directly by a utility or sold wholesale to utility buyers via a PPA	Allow customers to purchase a share of the farm and the energy produced by that farm

Advantages and disadvantages of solar farms

- Starting or subscribing to a solar farm can be a great way to save money, reduce your carbon footprint and make the most of rapidly changing solar technology.

PROS	**CONS**
Generate environmentally friendly energy	Have an upfront cost for property owners
Require little maintenance	They require a lot of space (but not on your property)
Typically have no upfront costs for subscribers	Only work when the sun is shining (and energy storage can be expensive)

Solar cell degradation analysis

- Reduction in solar panel efficiency with time
- Aging is the main factor affecting solar panel degradation, this can cause corrosion, and delamination, also affecting the properties of PV materials.
- Other degrading mechanisms affecting PV modules include Light-Induced Degradation (LID), Potential-Induced Degradation (PID), outdoor exposure, back-sheet failure and environmental factors.

Solar cell degradation analysis

- **Back-sheet failure** is another degradation cause, being the main cause of premature degradation. It is determined that 9% to 16% of PV modules suffer from backsheet failure
- **The delamination of the backsheet** or the formation of cracks in the material. When the backsheet fails, the inner components of solar panels are exposed to external agents, and the lifespan of PV modules is reduced
- **Tools to determine degradation** : visual inspection, infrared thermography, electroluminescence (EL), and performance

Reduction of Solar cell degradation

- **Quality of the materials:** Degradation mechanisms are partially caused by defects in the materials, so it can be concluded that PV modules with better higher-quality materials degrade at slower rates.
- **Additional materials and techniques** can be used to slow corrosion and reduce solar panel degradation. It has been proven that solar panel systems can last for at least 40 years
- **Assembly of the Modules:** PV modules may feature high-quality materials, but they require the strictest manufacturing processes to ensure top performance

Reduction of Solar cell degradation

- **Proper Installation** :When solar panels are being transported and handled during the installation, modules are subjected to mechanical stress. This stress can cause solar panel degradation due to back-sheet failure
- **Regular maintenance** is a vital tactic used to reduce solar panel degradation in large and small-scale applications. Reducing degradation from soiling and dust, resulting in an increased performance of the solar array
- **Weather conditions** : Analysis of the weather conditions (there is no control on this