Rooftop Solar PV System Designers and Installers

Training Curriculum

APEC Secretariat

March 2015


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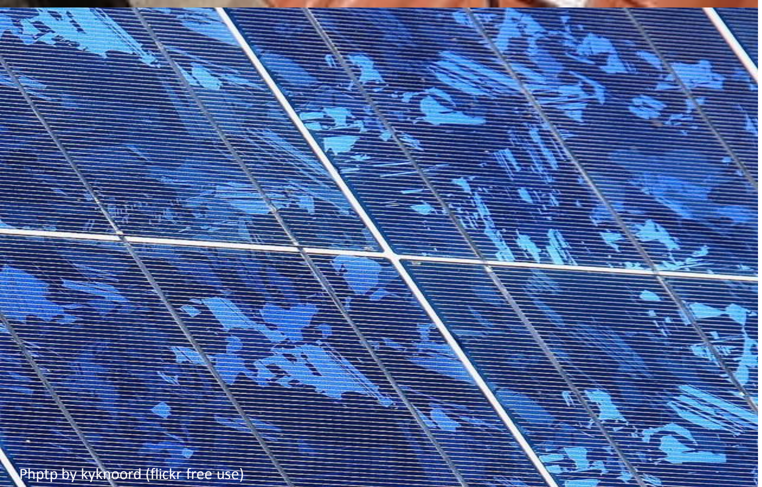
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PV MODULES

Training of PV Designer and Installer

Asia-Pacific Economic Cooperation

International Copper Association
Copper Alliance

castlerock consulting

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A. Basic principles of PV

B. Basic characteristics

C. Various type of PV cell

A. Basic principles of PV

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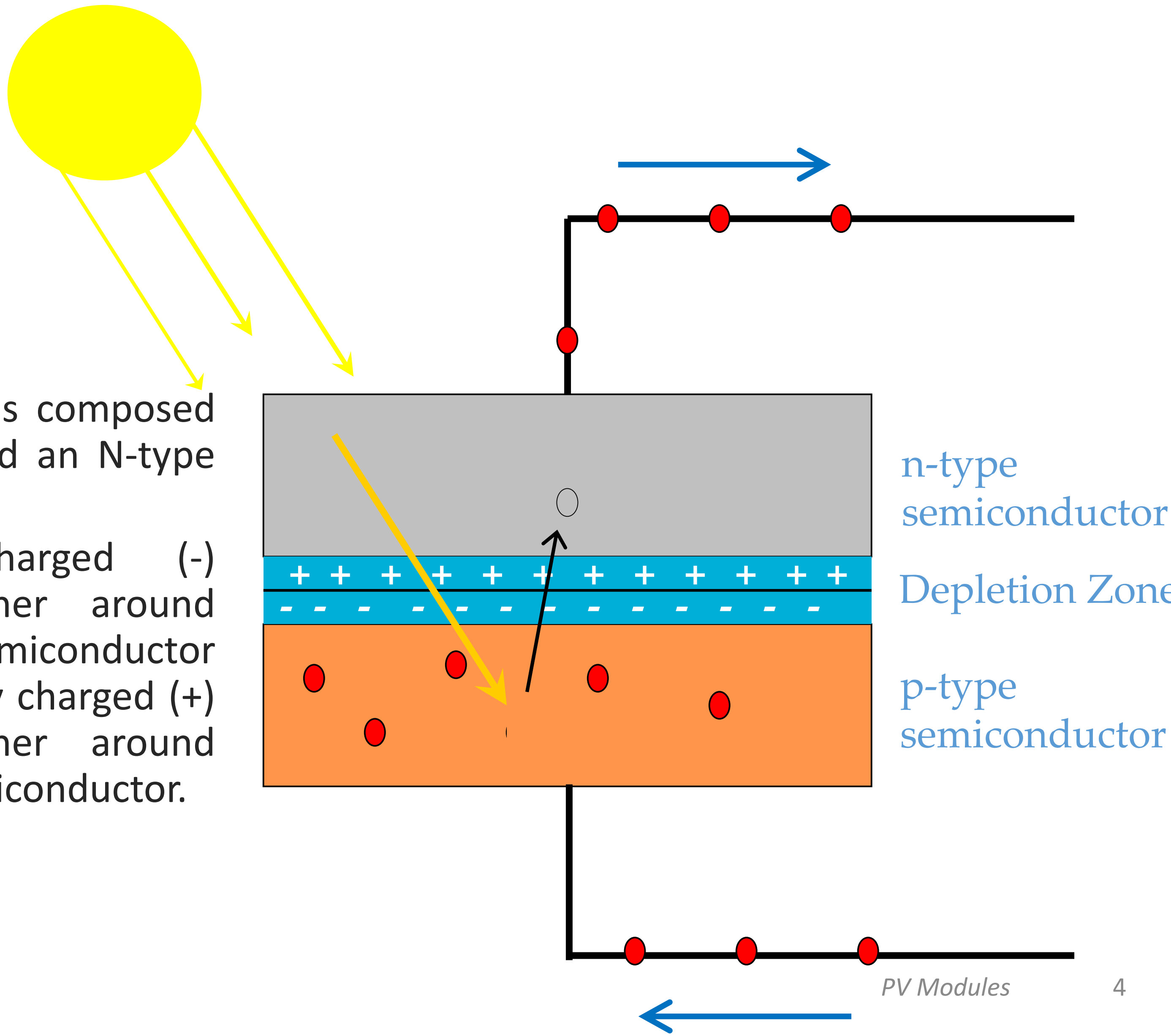
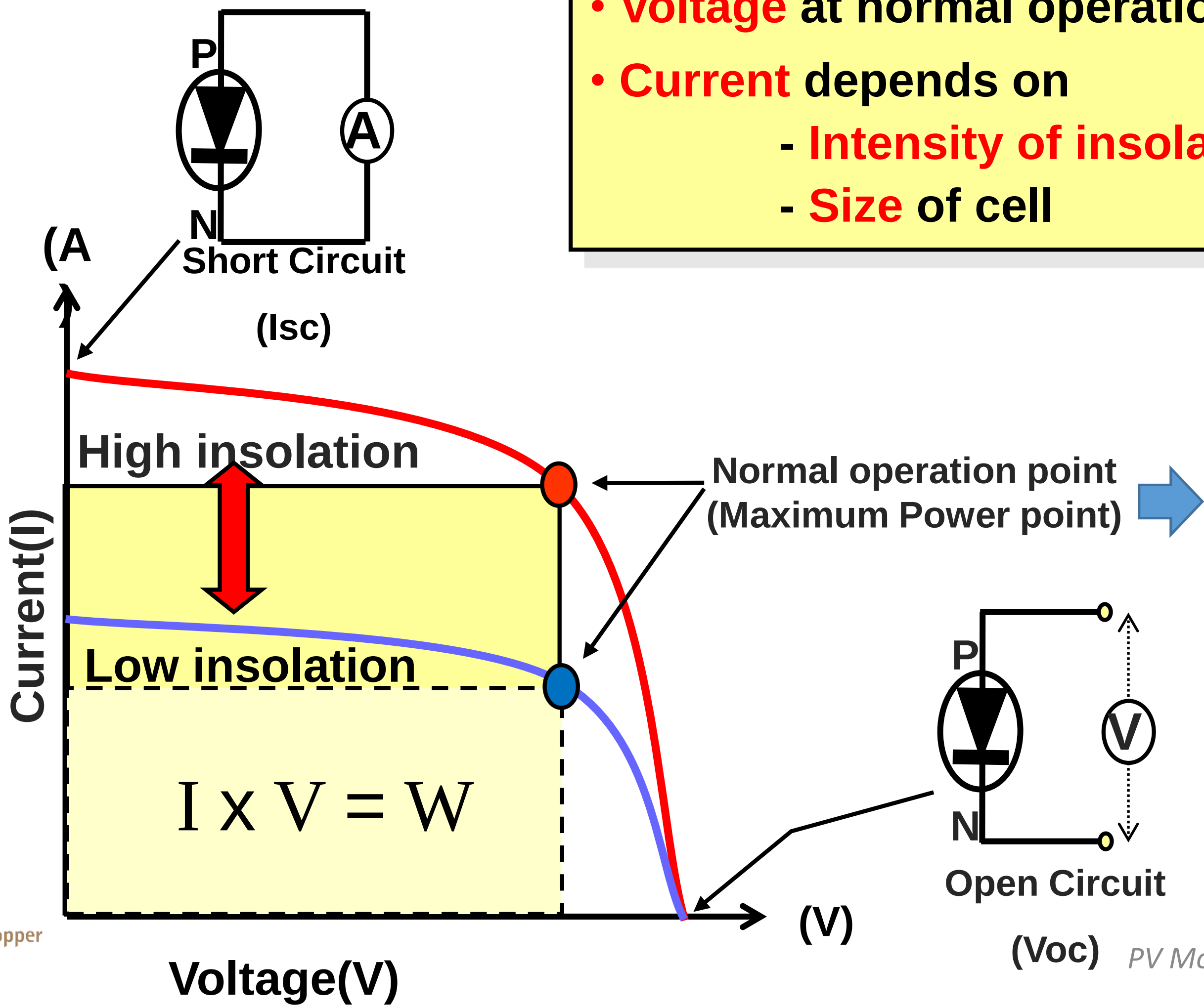


The solar cell is composed of a P-type and an N-type semiconductor.

Negatively charged (-) electrons gather around the N-type semiconductor while positively charged (+) electrons gather around the P-type semiconductor.

B. Basic Characteristics

- Voltage and Current of PV cell (I-V Curve)



- **Voltage at normal operation point**
- **Current depends on**
  - **Intensity of insolation**
  - **Size of cell**

This point measured as

- Vmp
- Imp

B. Basic Characteristics

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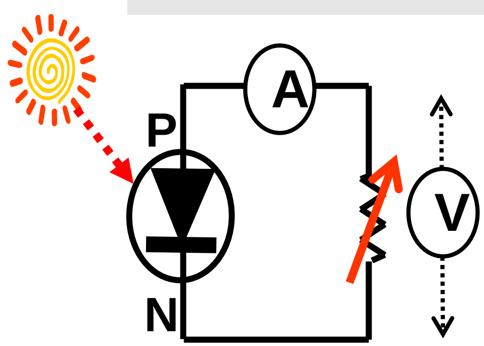
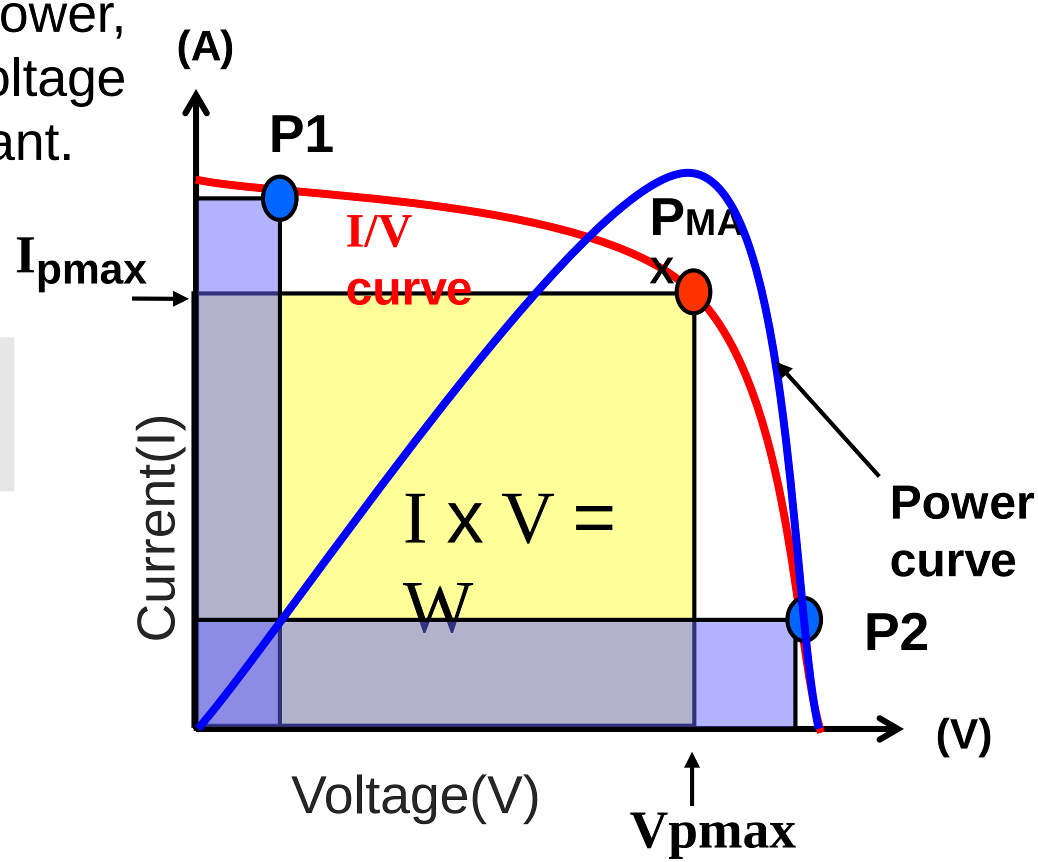
I / V curve and P-Max control

To obtain maximum power, current control (or voltage control) is very important.

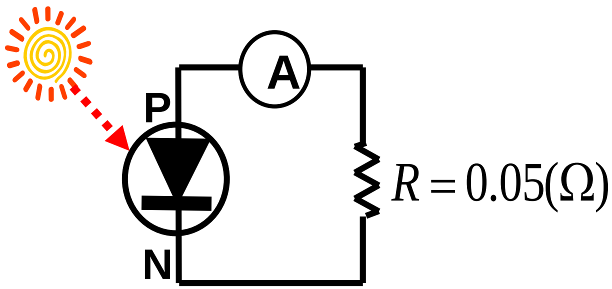
P- Max control

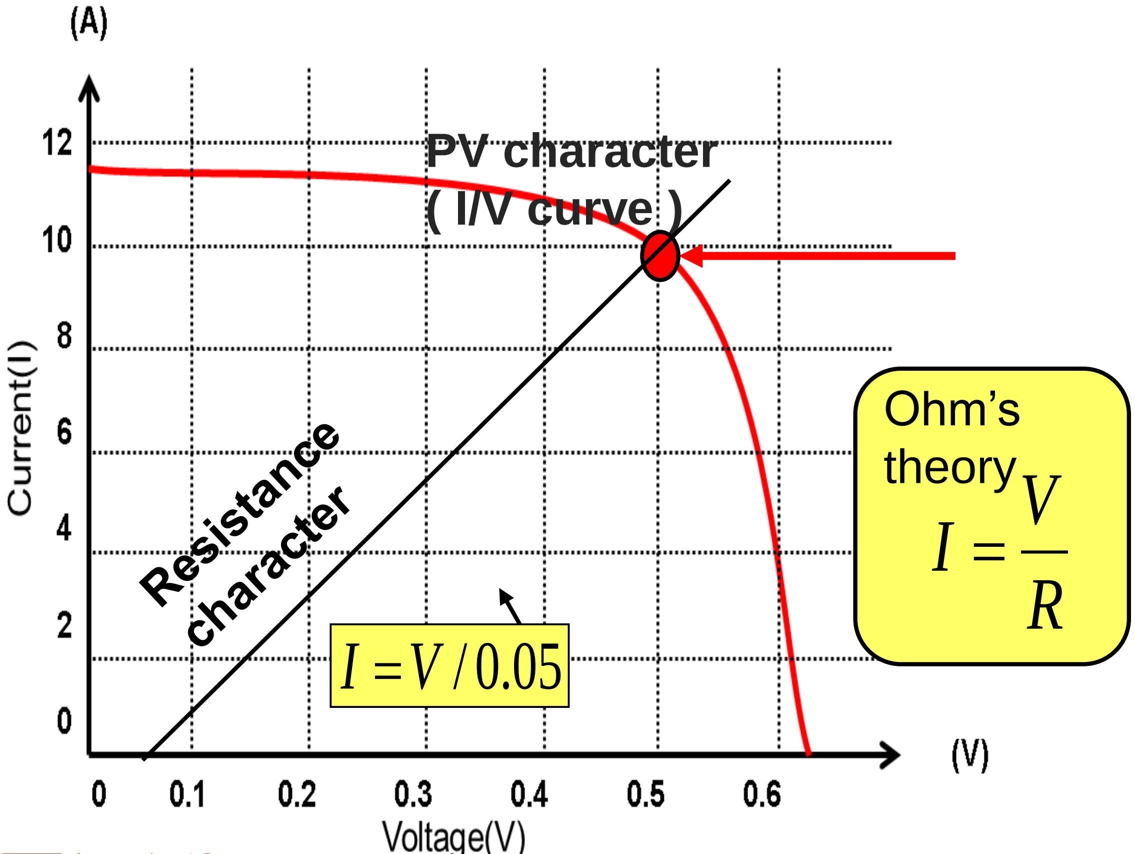




B. Basic Characteristics

Estimate obtained power by I / V curve





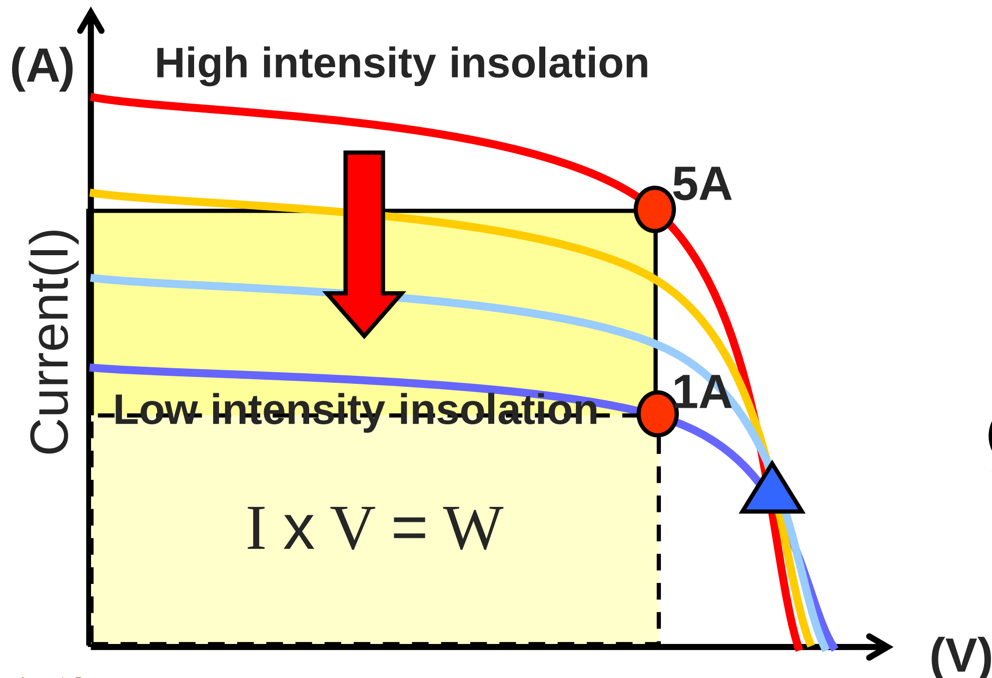
If the load has 0.05 ohm resistance, then the intersection point of the resistance and the IV curve will be the power point.

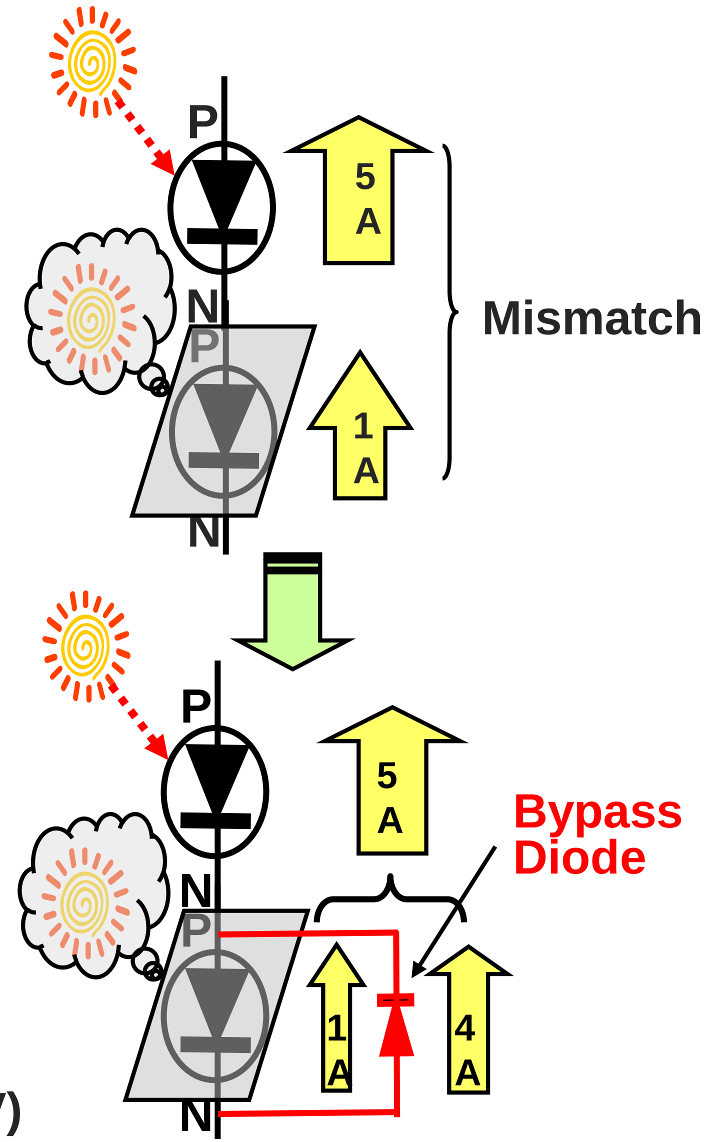
Then power is 10Vx0.5A =5 W

B. Basic Characteristic

I / V curve vs. Insolation intensity

- Current is affected largely by change of insolation intensity.
- Partially shaded serial cell will produce current mismatch. To avoid this from happening, a bypass diode isrequired





B. Basic Characteristic

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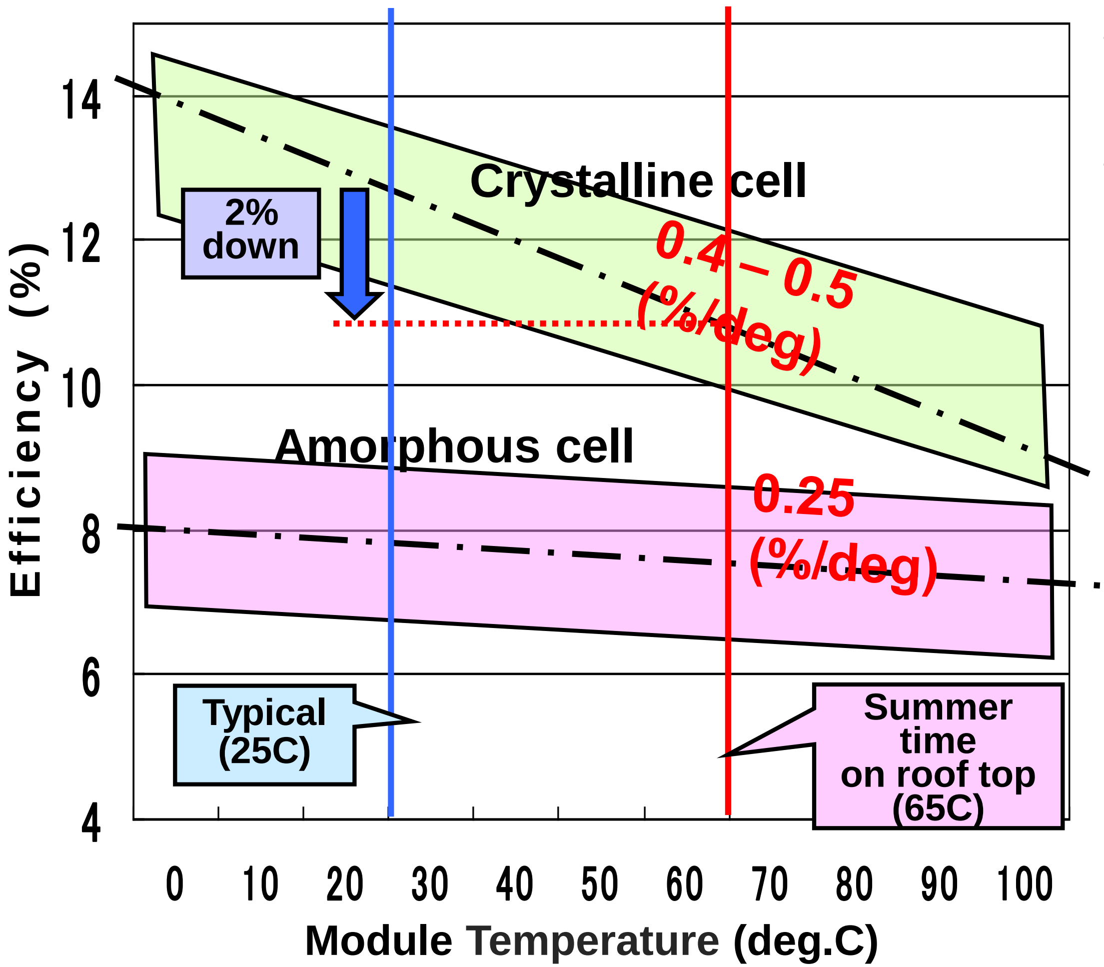
Temperature and efficiency



- When module temperature rises up, efficiency decreases.
- The module must be cooled by natural ventilation, etc.

C. Types of PV Modules

PV technologies are classified as first, second, and third generation. First generation technology is the basic crystalline silicon (c-Si). Second generation includes Thin Film technologies, third generation includes concentrator photovoltaics, organics, and other technologies that have yet to be commercialized on a large scale.

1. **First generation (Crystalline silicon technology)**

   Crystalline silicon cells are made from thin slices (wafers) cut from a single crystal or block of silicon. The type of crystalline cells depends on how the wafers are produced. The main types of crystalline cells are:

   - Mono crystalline (mc-Si)
   - Polycrystalline or multi crystalline (pc-Si)
   - Ribbon and sheet-defined film growth (ribbon/sheet c-Si)

   Crystalline silicon is the most common and mature technology representing anout 80% of the present-day market.

C. Types of PV Modules

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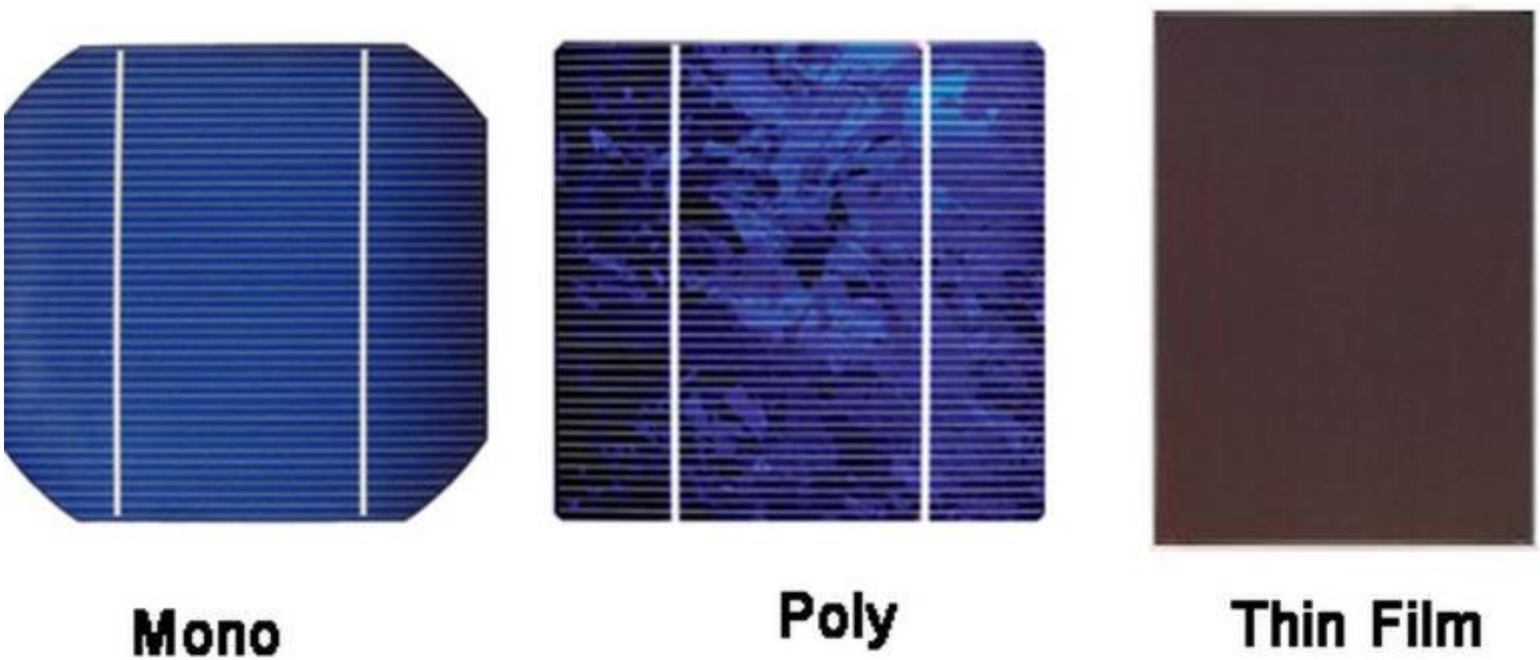

C. Types of PV Modules

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2. **Second generation (Thin films)**

   Thin film modules are constructed by depositing extremely thin layers of photosensitive material on to low-cost backing such as glass, stainless steel or plastic. Once deposited material is attached to the backing, it is laser-cut into multiple thin cells.

   Thin film modules are normally enclosed between two layers of glass and are frameless. If the photosensitive material has been deposited on a thin plastic film, the module is flexible. This creates the opportunity to integrate solar power generation into the fabric of a building (BIPV) or end-consumer application.

   Thin film types are commercially available:

   - Amorphous silicon (a-Si)

     Amorphous silicon can absorb more sunlight than c-Si structures. A lower flow of electrons is generated which leads to efficiencies that are currently in the range of 4 to 8%.

C. Types of PV Modules

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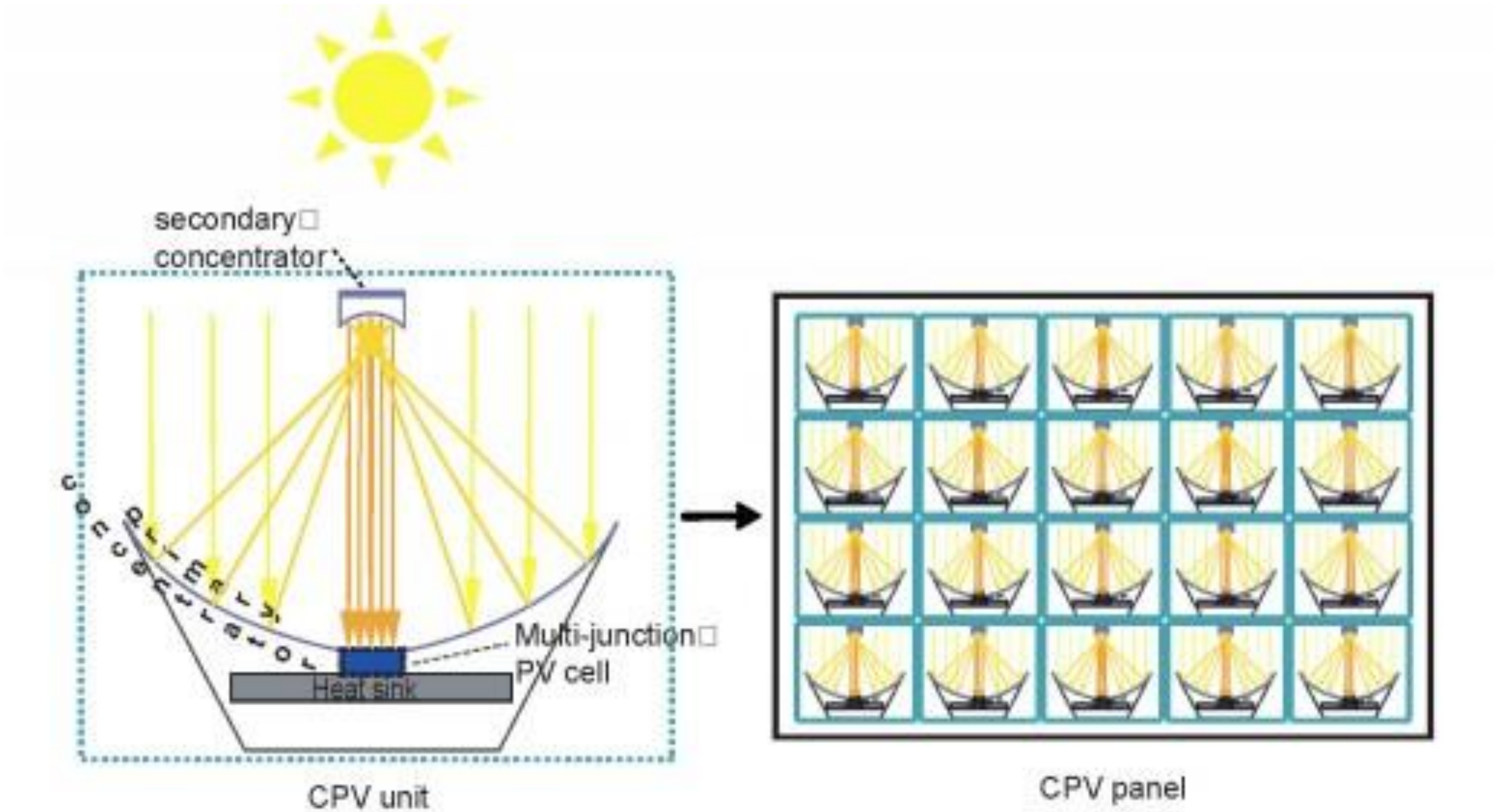
- Multi-junction Thin Film silicon (a-Si/µc-Si)
  Multi-junction silicon consist of an a-Si cell with additional layers of a-Si and micro-crystalline silicon (µc-Si) applied to the substrate. The µc-Si layer absorbs more light from the red and near-infrared part of the light spectrum. The increases efficiency by up to 10%.
- Cadmium telluride (CdTe)
  CdTe Thin Films cost less to manufacture and have a module efficiency of up to 11%. This makes it the most economical Thin Film technology currently available.
- Copper, indium, gallium, (di) selenide / (di) sulphide (CIGS) and copper, indium, (di) selenide /(di) sulphide (CIS)
  This Thin Film technology offer the highest efficiencies of all Thin Film technologies. Efficiencies of 20% have been achieved in the laboratory, which are close to the levels achieved with c-Si cells.

C. Types of PV Modules

3. **Third generation**
   Concentrator photovoltaics (CPV)
   Concentrator photovoltaics utilize lenses to focus sunlight on to solar cells. The cells are made from very small amounts of highly efficient, but expensive, semiconductor PV material. CPV cells can be based on silicon or III-V compounds (generally gallium arsenide or GaA). CPV systems use only direct irradiation. They are most efficient in very sunny areas which have high amounts of direct irradiation. The modules have precise and accurate sets of lenses which need to be permanently oriented towards the sun. This is achieved through the use of a double-axis tracking system.

C. Types of PV Modules

Concentrator photovoltaics (CPV)



C. Types of PV Modules

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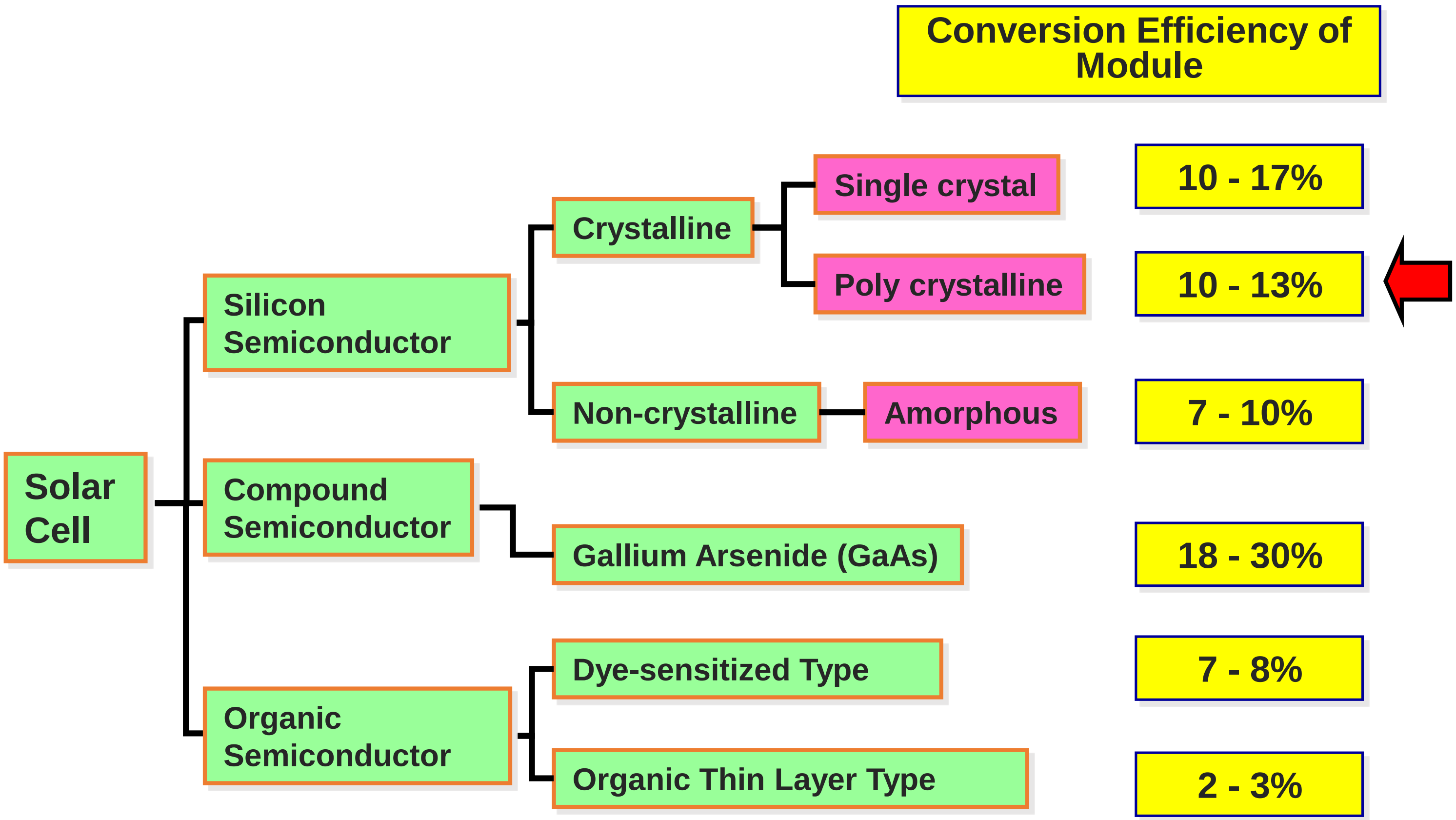


$$\left(\text{Conversion Efficiency} = \frac{\text{Electric Energy Output}}{\text{Energy of Insolation on cell}} \times 100\% \right)$$

C. Types of PV Modules

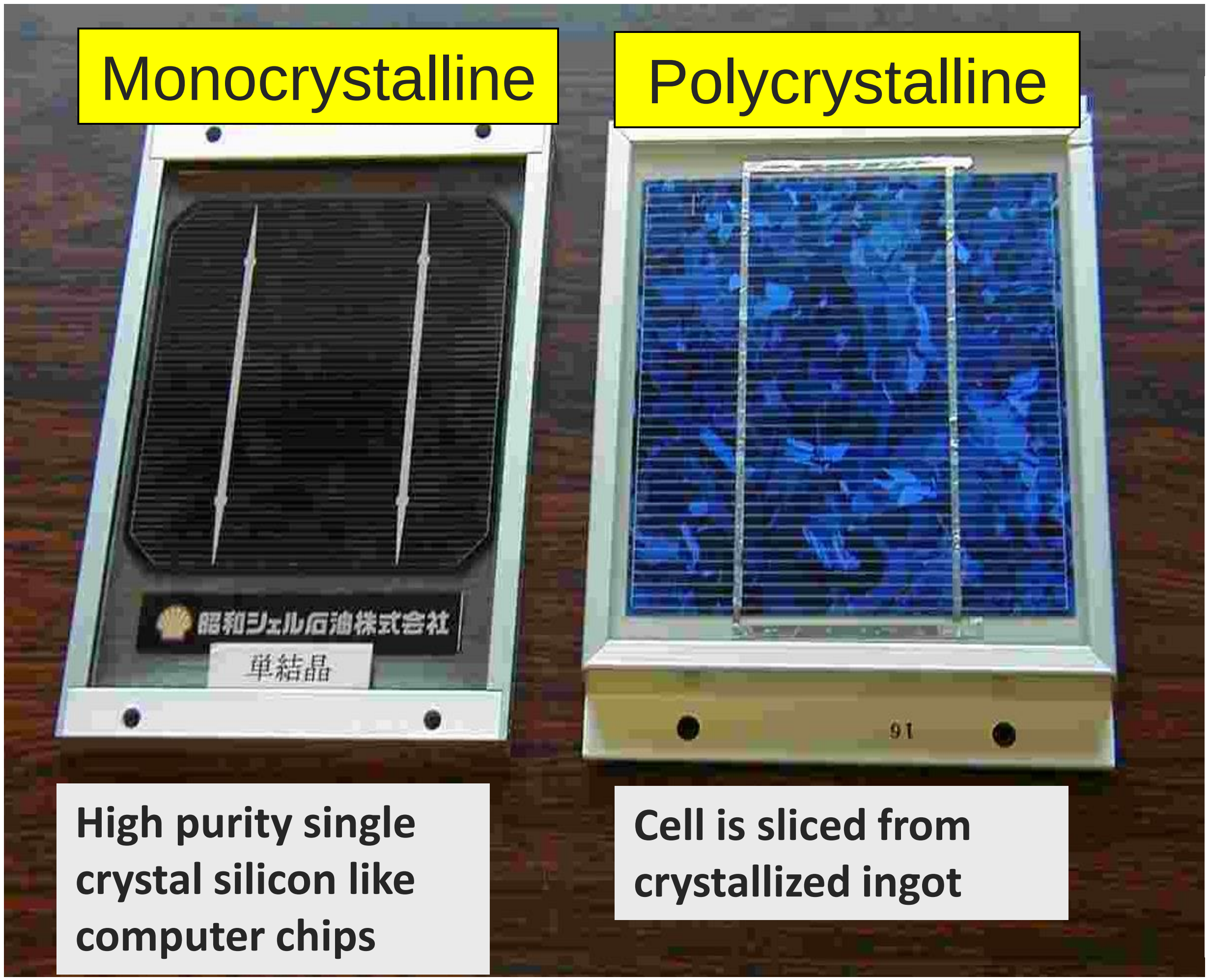
How Solar Cells are Made:

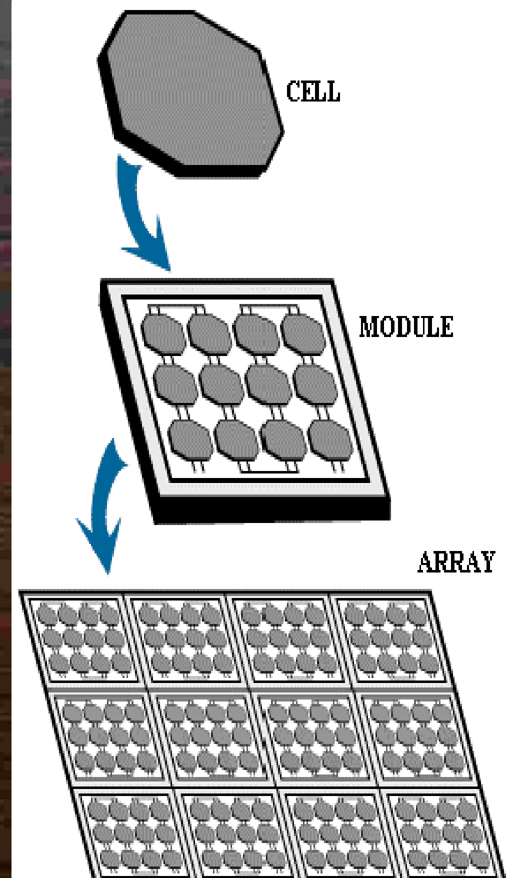
- Monocrystalline - https://www.youtube.com/watch?v=AMgQ1-HdElM
- Monocrystalline - https://www.youtube.com/watch?v=SOuyZWqhlNU
- Thin film - https://www.youtube.com/watch?v=QaDVlPlvVZI

How Solar PV Panels are Made:
https://www.youtube.com/watch?v=qYeynLy6pj8

C. Types of PV Modules

Crystalline cell (Single crystal and Poly crystalline Silicon)





C. Types of PV Modules

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Amorphous silicon PV cells

- Operating efficiency average of ~8-10%
- Makes up about 13% of PV market

C. Types of PV Modules

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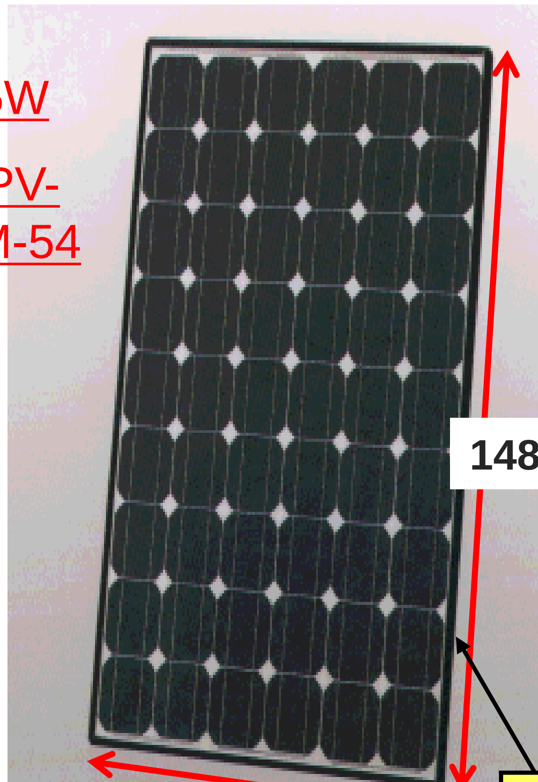
Single crystal

245W

CNPV-245M-54



1482mm

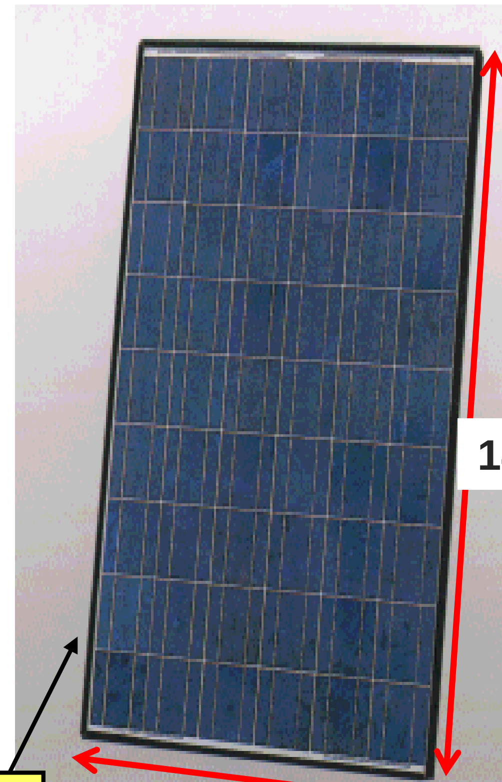
992mm

Efficiency is higher

Poly crystalline

210W

CNPV-210P-54



1482mm

992mm

Efficiency is lower

Approximately the same size

C. Types of PV Modules

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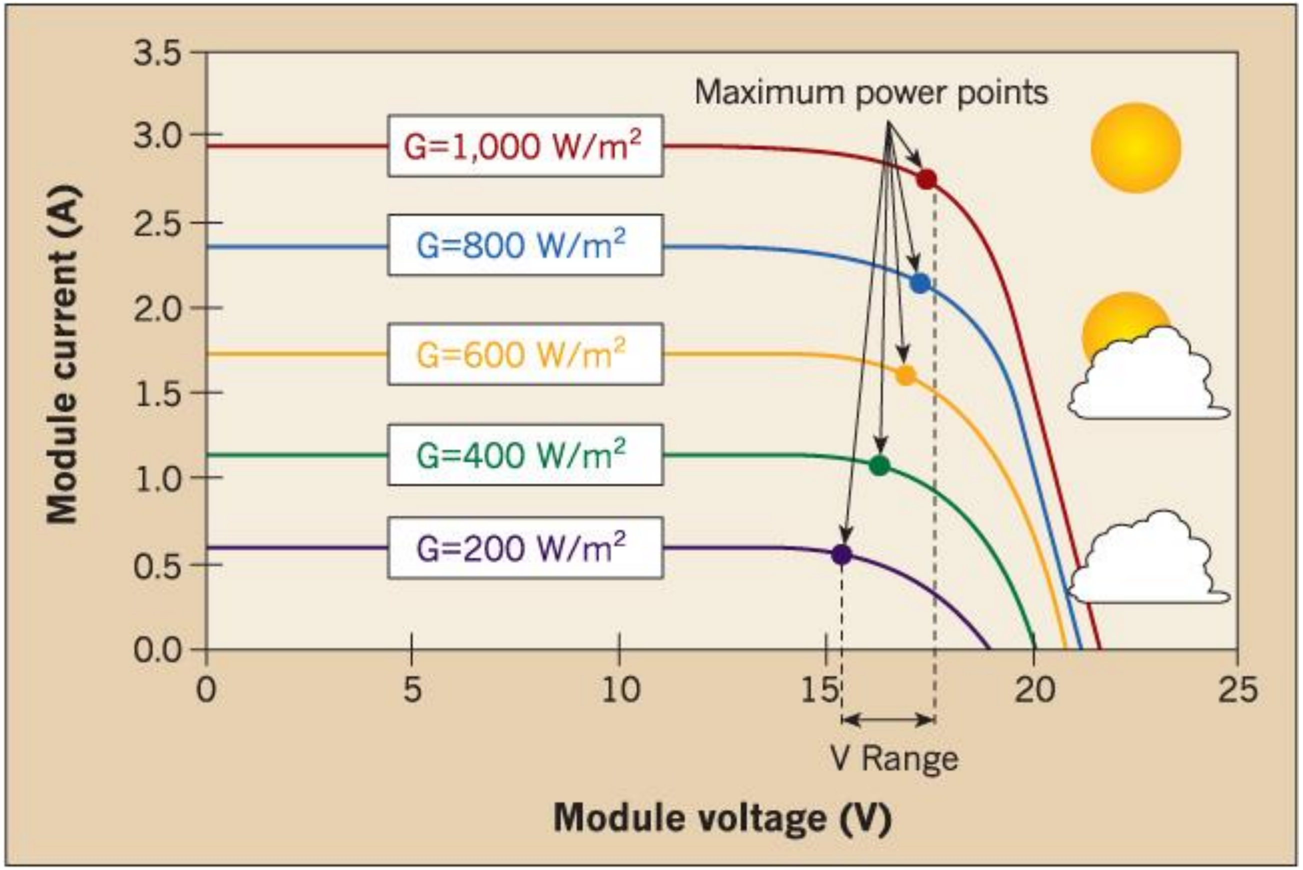
Commercial Module Efficiency							
Technology	Thin Film					Crystalline Silicon	
	(a-Si)	(CdTe)	CI(G)S	a-Si/ µc-Si	Dye s. cells	Mono	Multi
							
Cell efficiency Module efficiency	4-8%	10-11%	7-11%	7-9%	2-4% (LAB)	13-19%	11-15%
Area Needed per KW (for modules)	~ 15 m²	~ 9m²	~ 10m²	~12m²		~7m²	~8m²

Source: EPIA 2010. Photon international. March 2010. EPIA analysis
Efficiency based on Standard Test conditions.

Irradiance effect

Current rate is depends on the radiation



Source: http://ecmweb.com/

Temperature Effect

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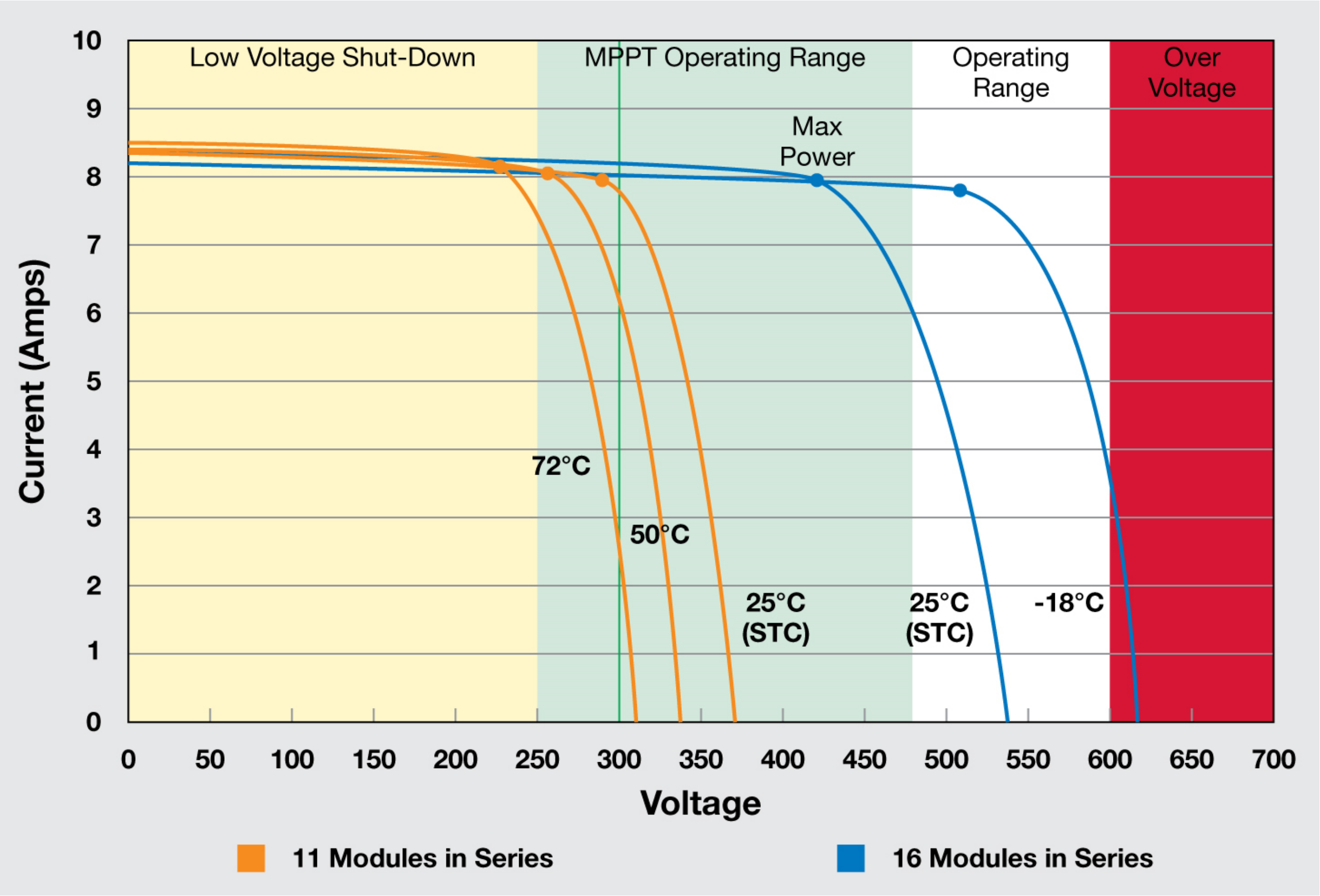
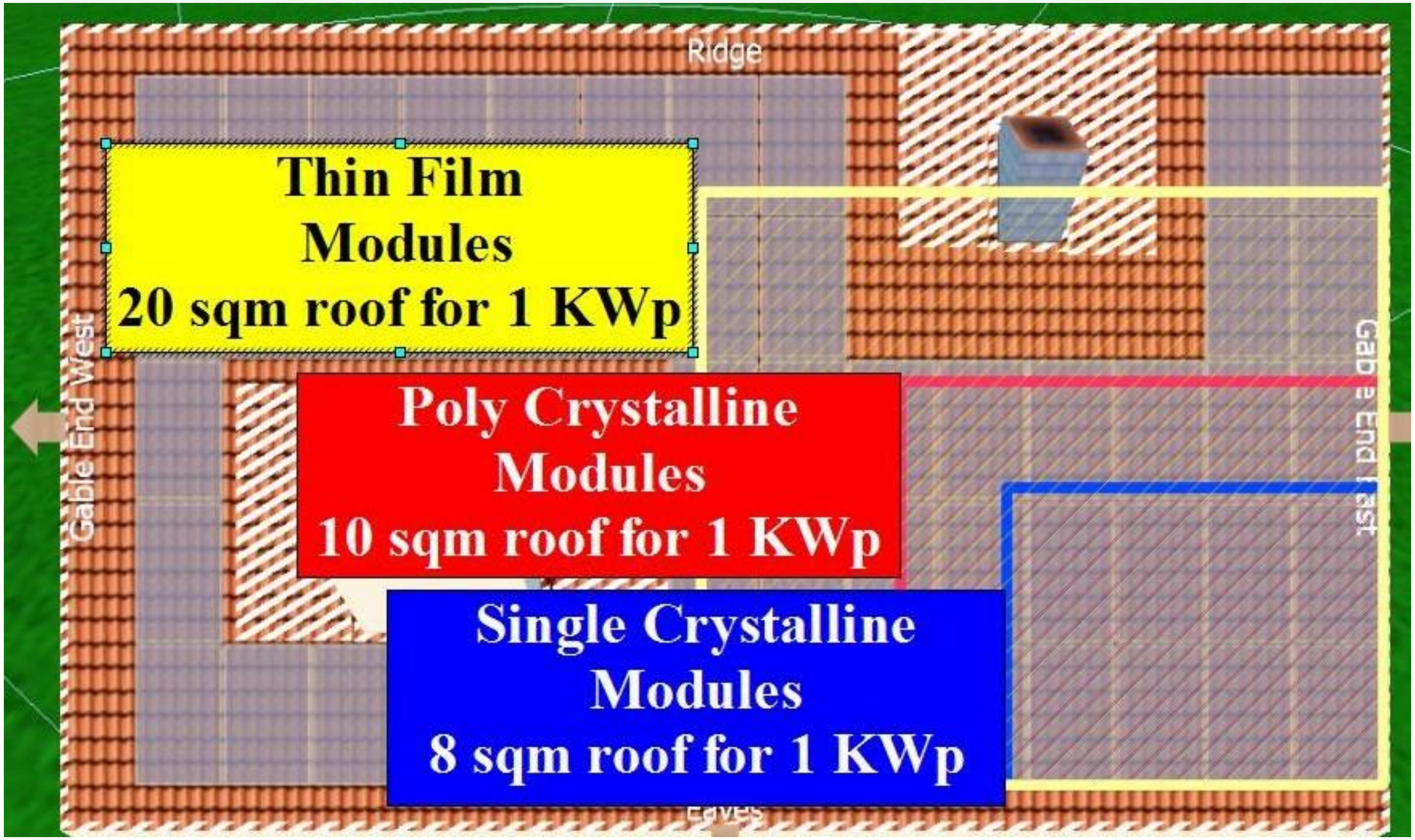
Too high temperature can reduce current



Source: http://www.homepower.com/

PV Modul Area Needed

The area is depend on efficiency



Source: http://www.europe-solar.de//

Standard Test Conditions

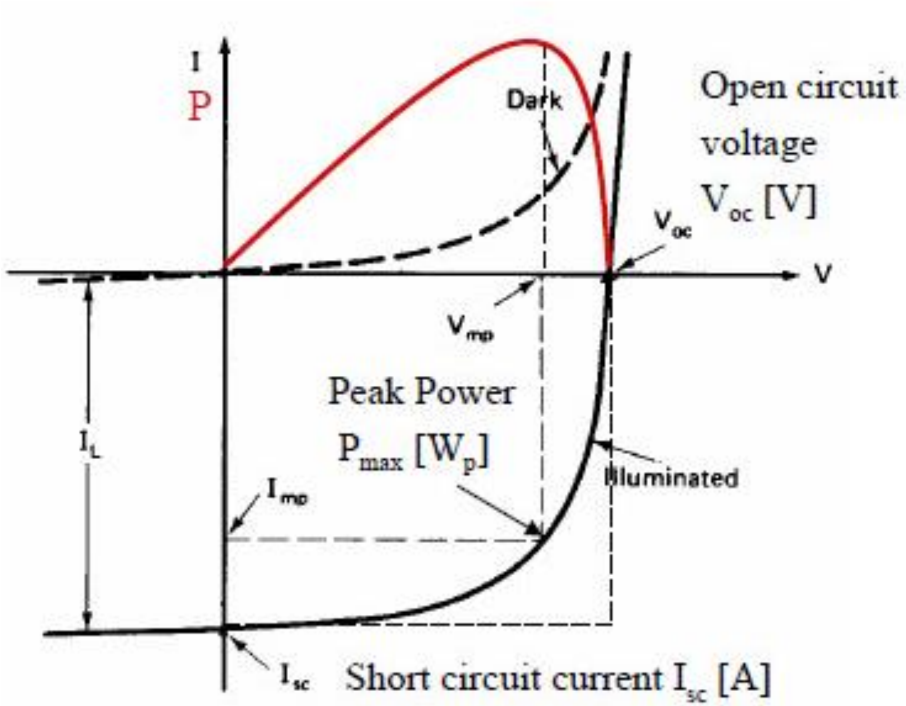
Wp (Watt Peak) indicates the nominal power of a solar cell at Standard Test Condition (STC):

Standard Test Condition:

- Air Mass 1,5 Spectrum
- Irradiance 1000 W/m^2
- Temperature 25^0C

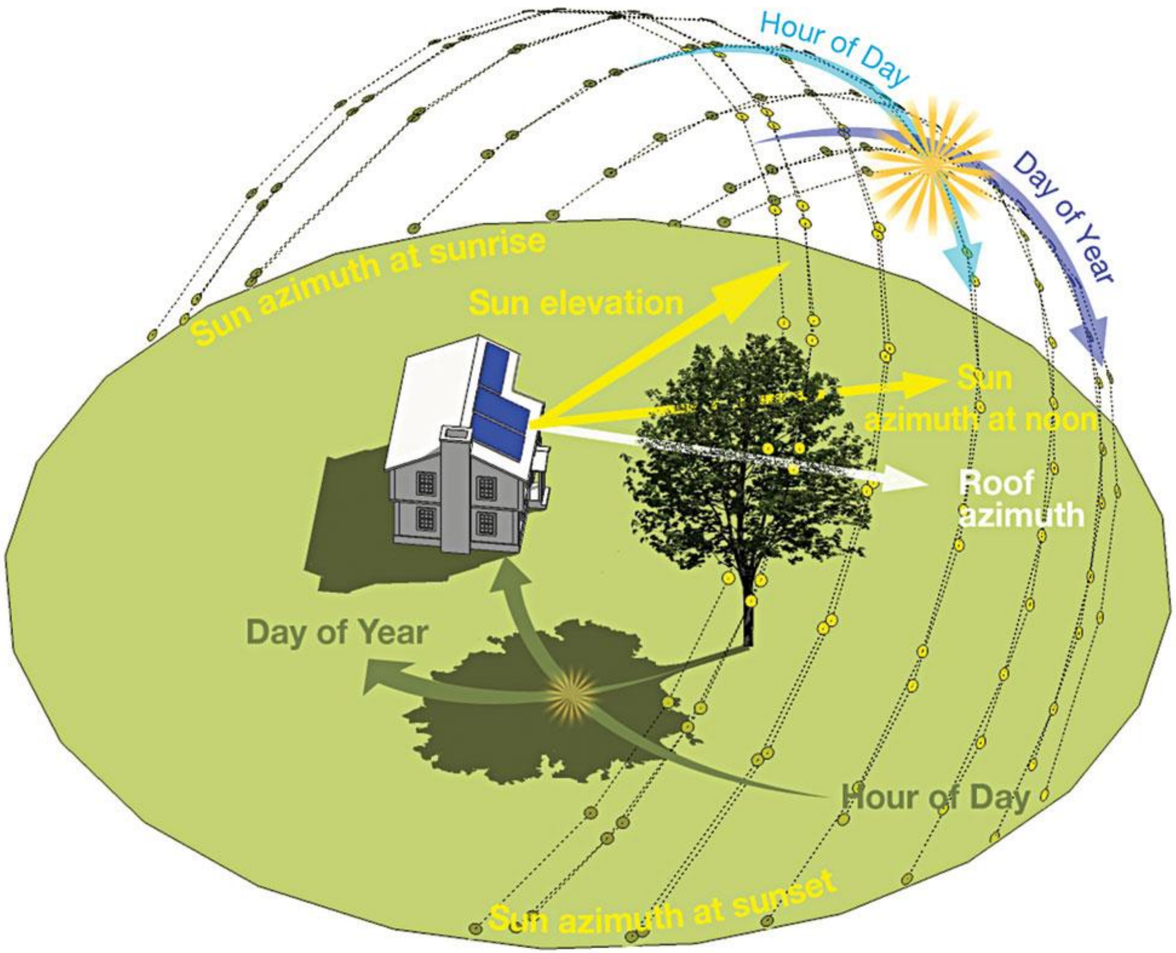
External Parameter

- Short Circuit Current
- Open Circuit Voltage
- Fill Factor
- Maximum Power
- Efficiency



Source: http://wesrch1.wesrch.com/

Shading



Source: http://www.homepower.com/

Shading

Crystalline

22% of the cells shaded

Reduced output by ~80%

33% of the cells shaded

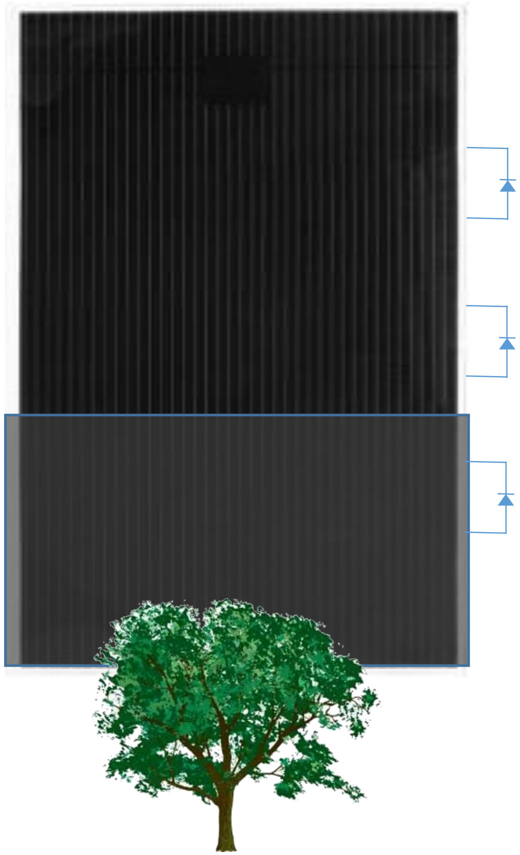
Reduced output by ~33%

Shading

Thin Film

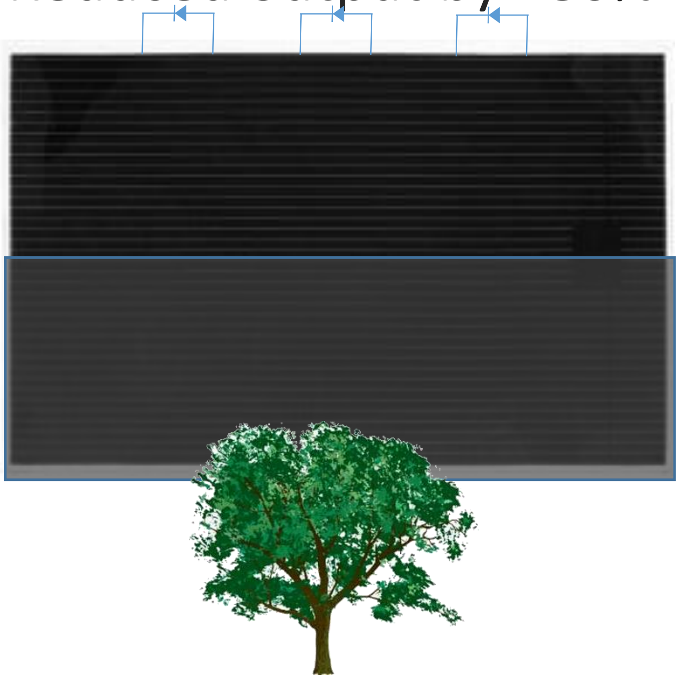
33% of the cells shaded

Reduced output by ~33%



50 % of the cells shaded

Reduced output by ~80%



Comparison Crystallin and Thin Film

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Advantages

Crystalline Silicon	a-Si Thin-Film
Highest power per area	Output less affected by temperature
Requires less racking & support material	Less manufacturing materials used
Fewer modules means lower shipping costs	Lower cost per watt
Large number of module choices	Good aesthetics for building-integrated applications
Greatest inverter flexibility	Less embodied energy (faster energy payback)
	Non-glass substrates possible
	More shade tolerant

Comparison Crystallin and Thin Film

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Disadvantages

Crystalline Silicon	a-Si Thin-Film
Higher cost per watt	Lower power per area
High temperatures affect output more	Takes months to stabilize output
Low shade tolerance	Twice as much rack material required
Individual cell visibility	More modules mean higher shipping costs
	Lower series-string capacity
	Less suitable for battery charging
	Requires more combiner boxes
	Limited inverter flexibility
	Fewer module manufacturer choices

IEC Standard

- IEC 62215 => Crystalline Technology
- IEC 61646 => Thin film terrestrial photovoltaic (PV) modules
- IEC 61730 => Photovoltaic (PV) module safety qualification
- EN 50380 => Datasheet and nameplate information for photovoltaic modules

Limitation of the IEC Standards

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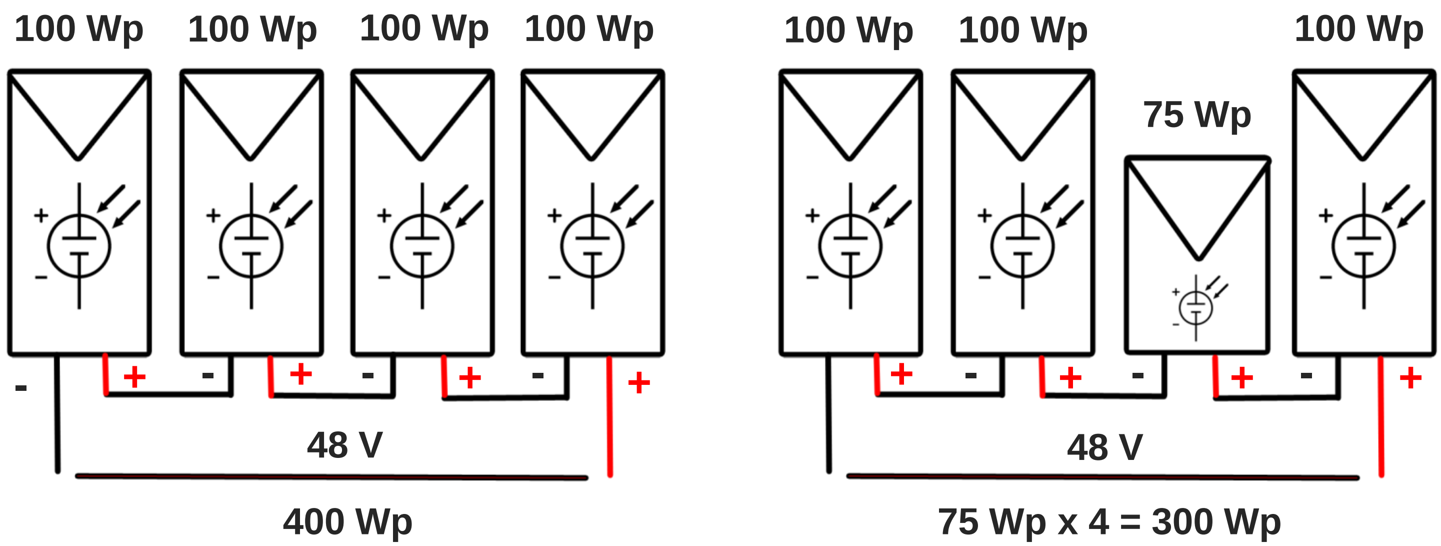
- Accelerated tests are used to simulate stresses endured over the lifetime of the PV Module

  E.g.: damp heat cycles of 1000hrs in the IEC 61215 standards
- However, one cannot simulate the entire 20 year lifetime
- Test Condition may not be relevant to the PV plant site
- Tests do not cover all failure mechanisms

Mismatch due to inhomogeneity in a modules



- Modules wattages are added together
- Voltage are added together
- Current remains the same

- Voltages are added together
- Current will be that of the smallest module, less power

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