BE1M13VES

Manufacturing of Electrical Components

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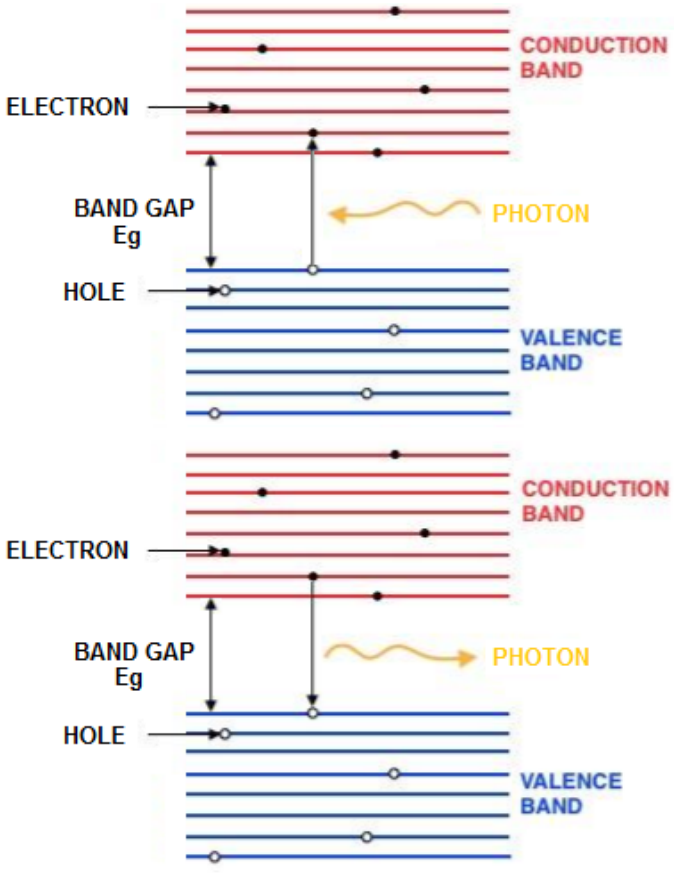
Overview

TOPIC

Photoelectric effect

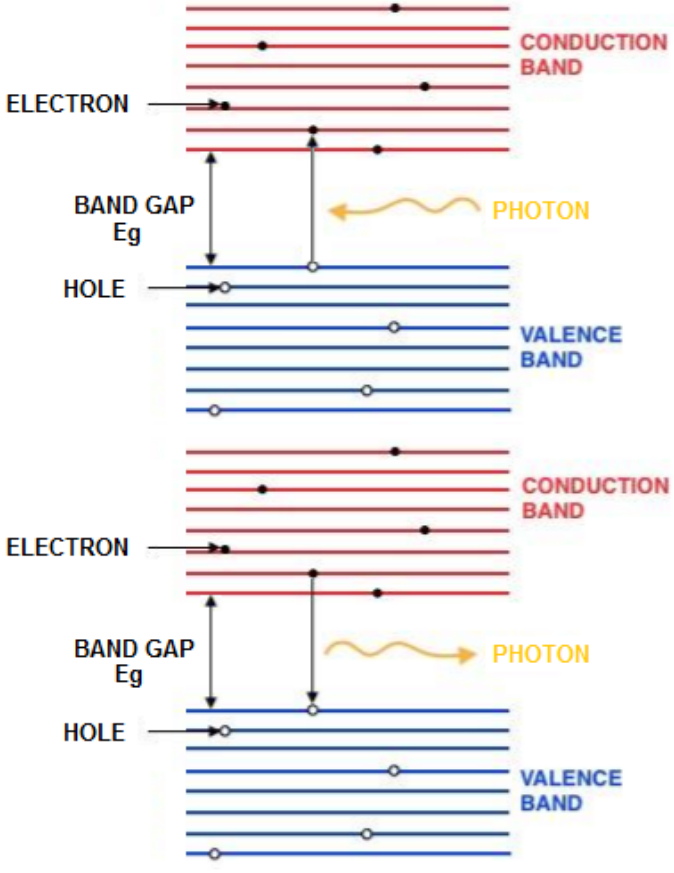


- Each photon carries particular amount of energy.
- Collision with electron may push the electron to higher energy state.
- The energy of the photon must be: $E \geq h \cdot f$

  h ... Planck constant
  f ... photon frequency

- Rest of the energy is converted to heat.

Photoelectric effect



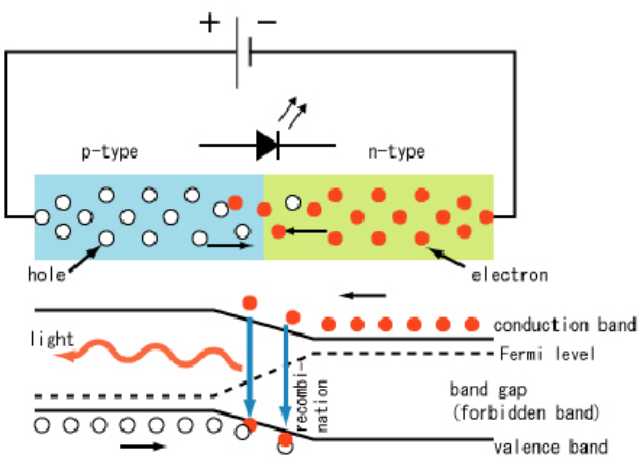
- The energy is released as photon during recombination.
- The photon wavelength λ is given by the band gap:

$$f = \frac{E_g}{h} = \frac{c}{\lambda}$$

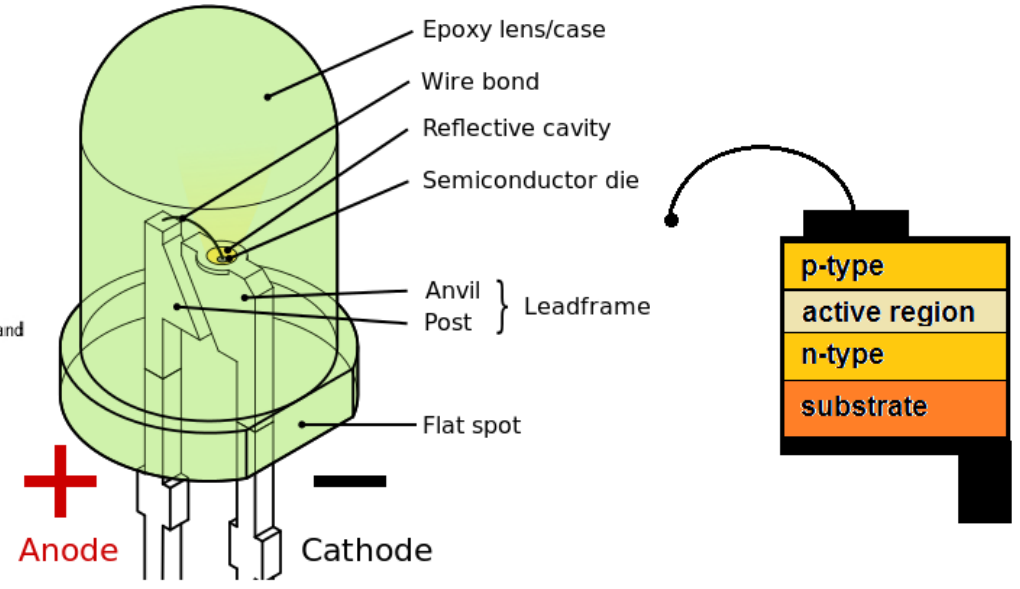
c ... speed of the light

- Recombination process is used in LEDs.

Light Emitting Diode



Source: http://www.bcnorthernlights.com/learn-to-grow-your-own/how-do-hid-lights-work

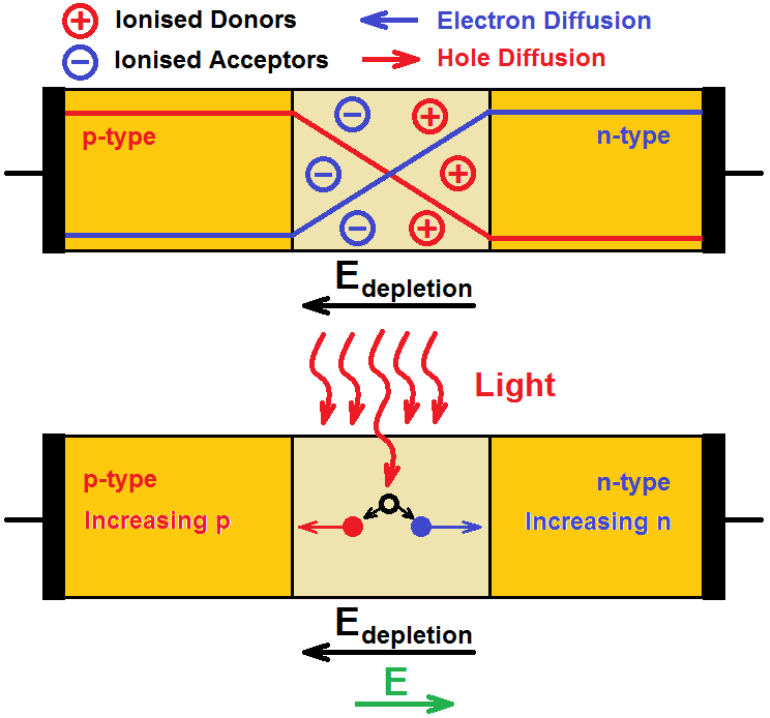


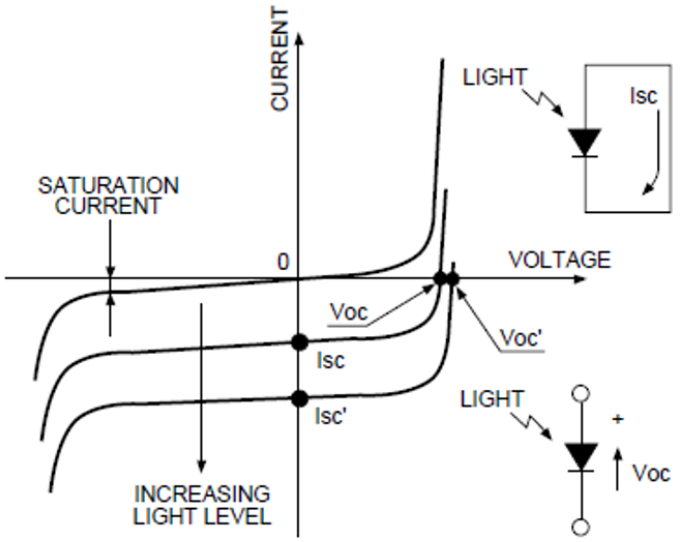
Source: https://core-electronics.com.au/tutorials/all-about-leds.html

- Color depends on the bandgap:
  InGaN (blue, UV, green), AlGaInP (yellow, orange), AlGaAs (red, IR), GaP (yellow, green)
- Similar characteristic to ordinary diode - higher threshold voltages (IR 1,2 V; RED 1,8 V; YELLOW 2,2 V; BLUE 3,6 V).

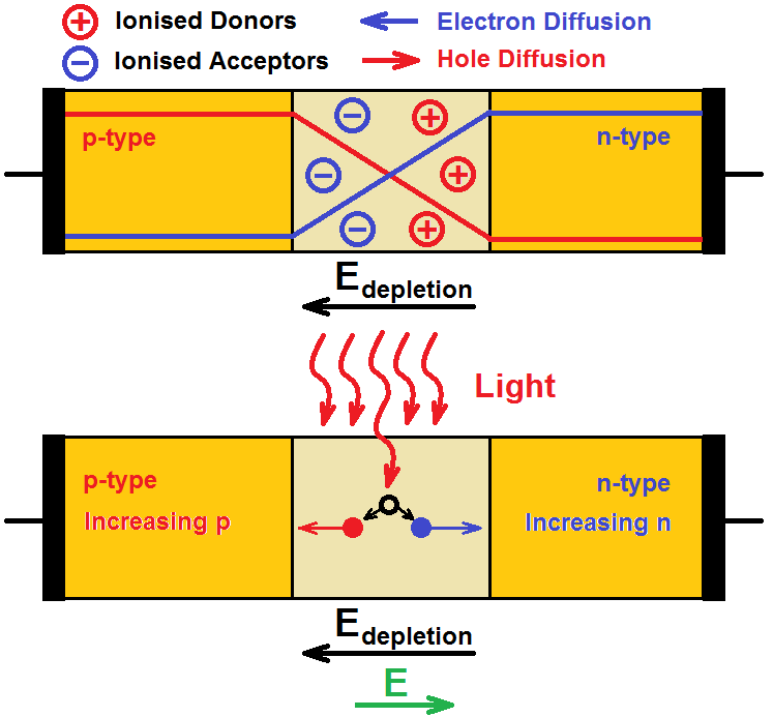
Photodiode

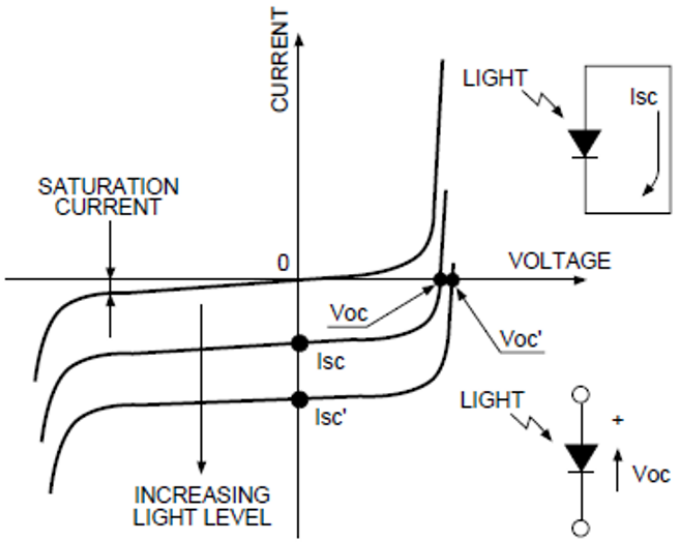
The PN junction is accessible to light via anti-reflection layer. The light creates other pairs of electron and holes, that are swept by the electric field of depletion area to the **n** (electrons) and **p** (holes) part.





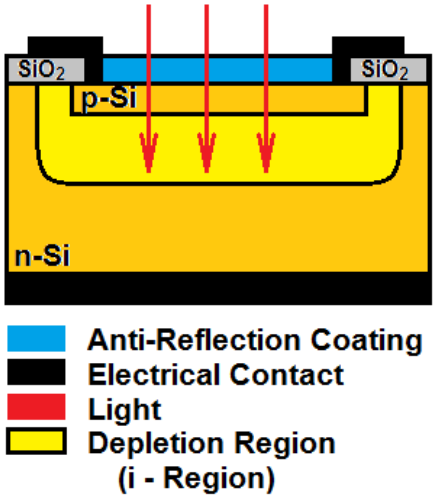
Photodiode

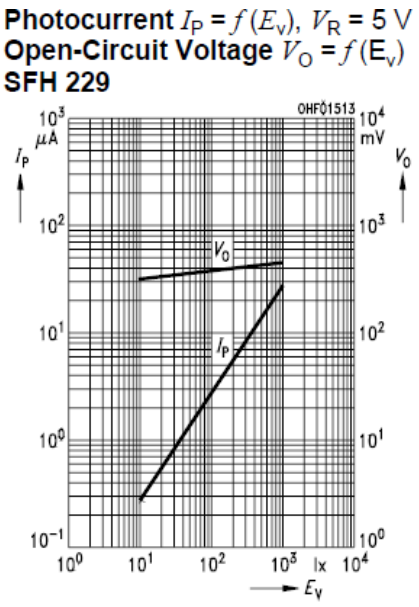




Additional charge creates electric field that reduces the electric field of depletion area. Charge imbalance generates voltage across the terminals. The maximum open-circuit voltage corresponds to diode characteristic.

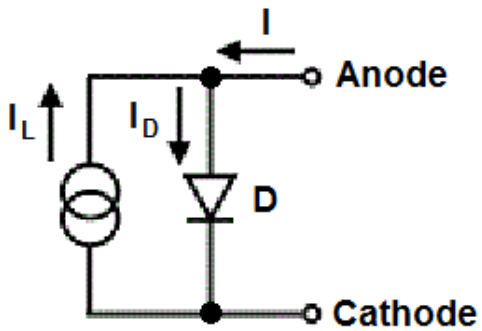
Photodiode - Technology





- The PIN diode construction is often used to increase the size of depletion area.
- i-region is intrinsic or slightly doped area. Other parts are highly doped to get ohmic contact with leads.

VA Characteristic



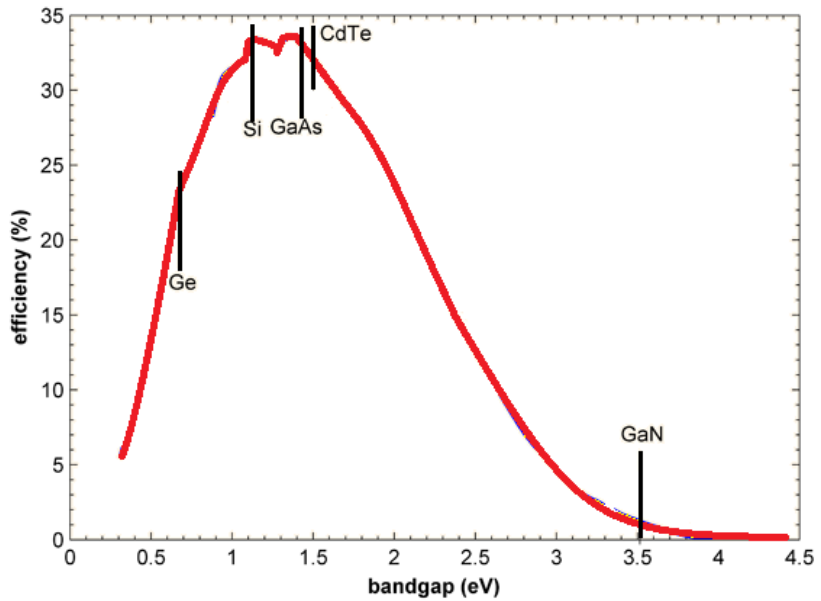
Modified Shockley Equation

$$I = I_D - I_L$$

$$I = I_0 \left(e^{\frac{U \cdot e}{n \cdot k \cdot T}} - 1 \right) - I_L$$

- I_L is the short-circuit current created by the incoming light.
- The equation above also defines temperature behavior of photodiodes and solar cells.
- The characteristic is also dependent on resistances of the leads (serial resistance should be included to the scheme).

Photo-Effect Efficiency



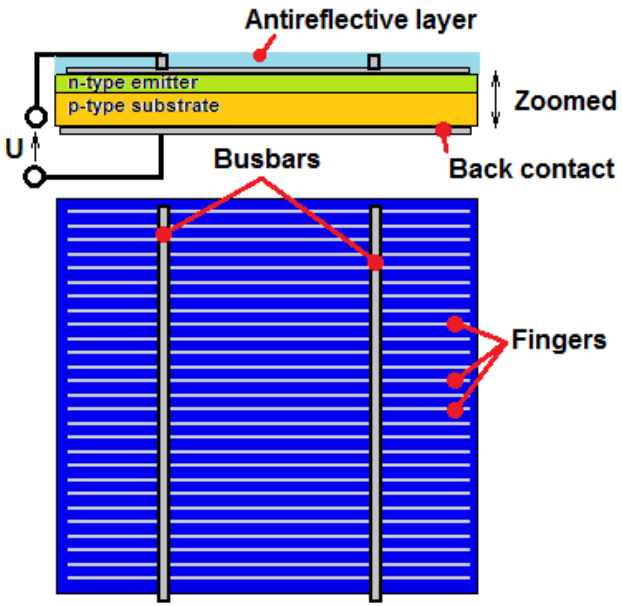
Material		Band Gap (eV)
Si	Silicon	1.11
Ge	Germanium	0.67
CdTe	Cadmium telluride	1.5
Cu_2O	Copper oxide	2.1
Cu_3N	Copper nitride	1.75
GaP	Gallium phosphide	2.26
GaAs	Gallium arsenide	1.43
PbS	Lead sulfide	0.37
Si_3N_4	Silicon nitride	5
C	Diamond	5.5
SiO_2	Silica	9

Source: https://www.e-education.psu.edu/eme812/node/534

- Energy higher than band gap energy is dissipated as heat.
- Most of the electrons are unable to cause photo-effect if the band-gap is to high.

TOPIC

Solar Cell

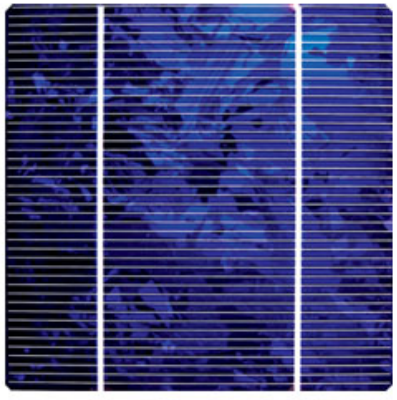


- Solar cells increase the size of active photodiode area to get most of the power from incoming light.
- The contacts are made from silver printed on the semiconductor layer (screen printing).

- The Anode contact covers whole rear side of the cell.
- Bus bars are used to connect cells together in the panel.
- Reflective layer increased the light absorption.

Solar Cell - Materials

Monocrystalline silicon



Polycrystalline (multicrystalline) silicon

Amorphous silicon (Thin-film)

Monocrystalline silicon

- oldest type, made from pure silicon crystal, iridescent blue or black color,
- \+ high efficiency - typical ≈15 % (up to 22-24 %), very durable,
- \- efficiency gradually decreases (about 0.5 % per year), brittle,
- \- complicated manufacturing (from silicon slices), expensive.

Solar Cell - Materials

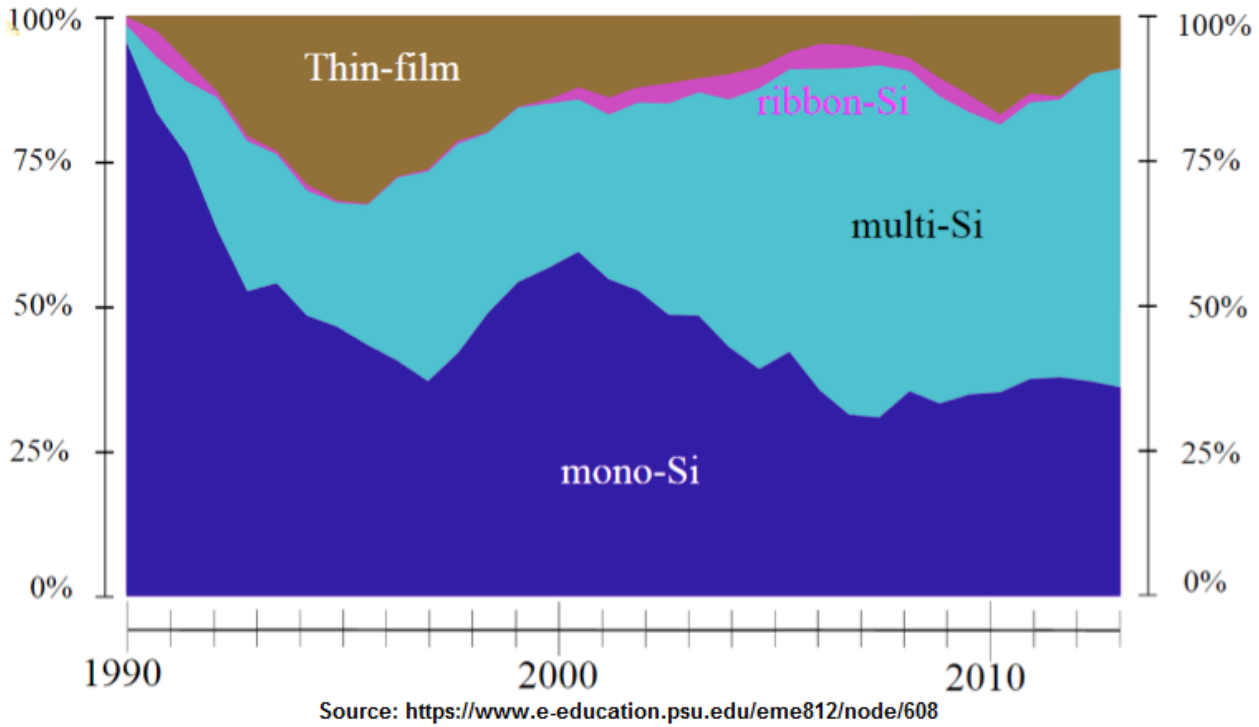
Polycrystalline silicon

- made by assembling grains and plates of silicon crystals, mosaic-like appearance,
- \+ good efficiency - typical ≈12 %, very durable, cheaper technology - manufacturing smaller grains is less complicated,
- \- less efficient than monocrystalline Si, brittle.

Amorphous silicon

- deposition of silicon film onto substrate glass, dark colors (black, brown),
- \+ small amount of Silicon ⇒ cheap, several substrates can be used for deposition ⇒ flexible solar cell on plastic substrates,
- \+ less prone for overheating,
- \- poor efficiency - typical ≈6 %.

Solar Cell - Materials

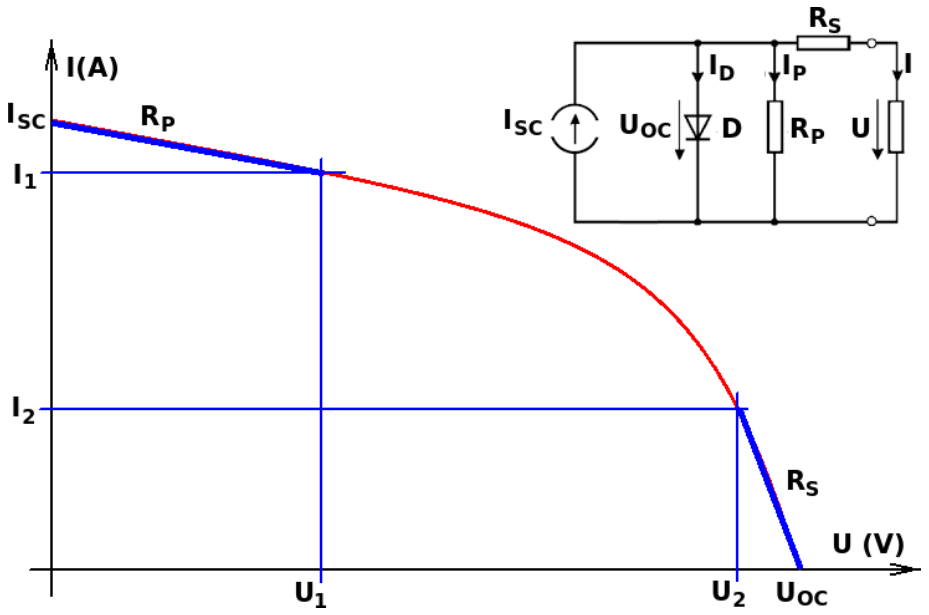


Source: https://www.e-education.psu.edu/eme812/node/608

Other thin film technologies

- Cadmium Telluride, CdTe: toxic Cd, high efficiency (16 %).
- Copper Indium Gallium Selenide (CIGS): high efficiency (up to 19 %), problematic deposition quality.

Equivalent circuit



U_{OC} ... open-circuit voltage

I_{SC} ... short-circuit current

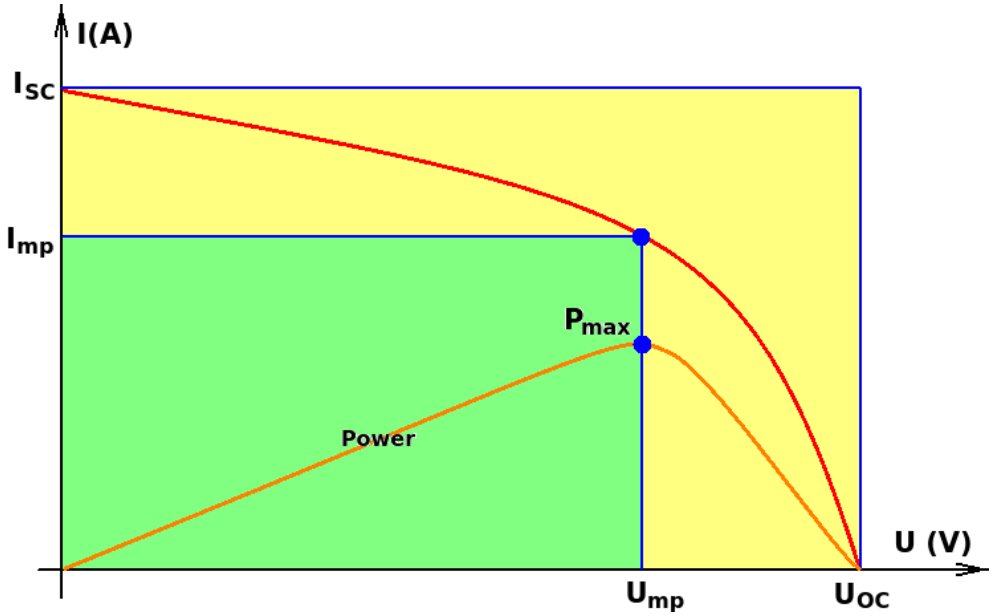
R_P ... shunt res., defects

R_S ... serial res., leads

$$R_P = \frac{U_1}{I_{SC} - I_1}$$

$$R_S = \frac{U_{OC} - U_2}{I_2}$$

Power Got from the Solar Cell



Fill Factor

- it defines the utilization of the solar cell,
- maximum varies with different materials,
- affected by R_S and R_P values!!!

$$FF = \frac{U_{mp} \cdot I_{mp}}{U_{OC} \cdot I_{SC}}$$

Commercial:

$$FF \approx 0.83 - 0.85$$

Efficiency:

$$\eta = \frac{U_{OC} \cdot I_{SC} \cdot FF}{P_{in}}$$

P_{in} ... incoming solar power

Solar Panel

- interconnected several solar cells together,
- serial connection increase the open-circuit voltage,
- parallel connection increase the short-circuit current.
- Interconnection of several panels creates solar arrays.