Greenhouse Gases Mitigation CO_2 Capture and Utilization

Topic No: 8

©Marek.Staf@vscht.cz

Table of contents

1. Definition of photovoltaic phenomenon
2. Principle of PV cell function
3. Evolution of PV cells – 1st to 3rd generation
4. Construction and manufacture of the PV panels
5. Overview of PV issues requiring development
6. Environmental impacts of PV cells production
7. Assembly of a small domestic PV power plant
8. Flat and vacuum solar collectors

What does photovoltaics mean?

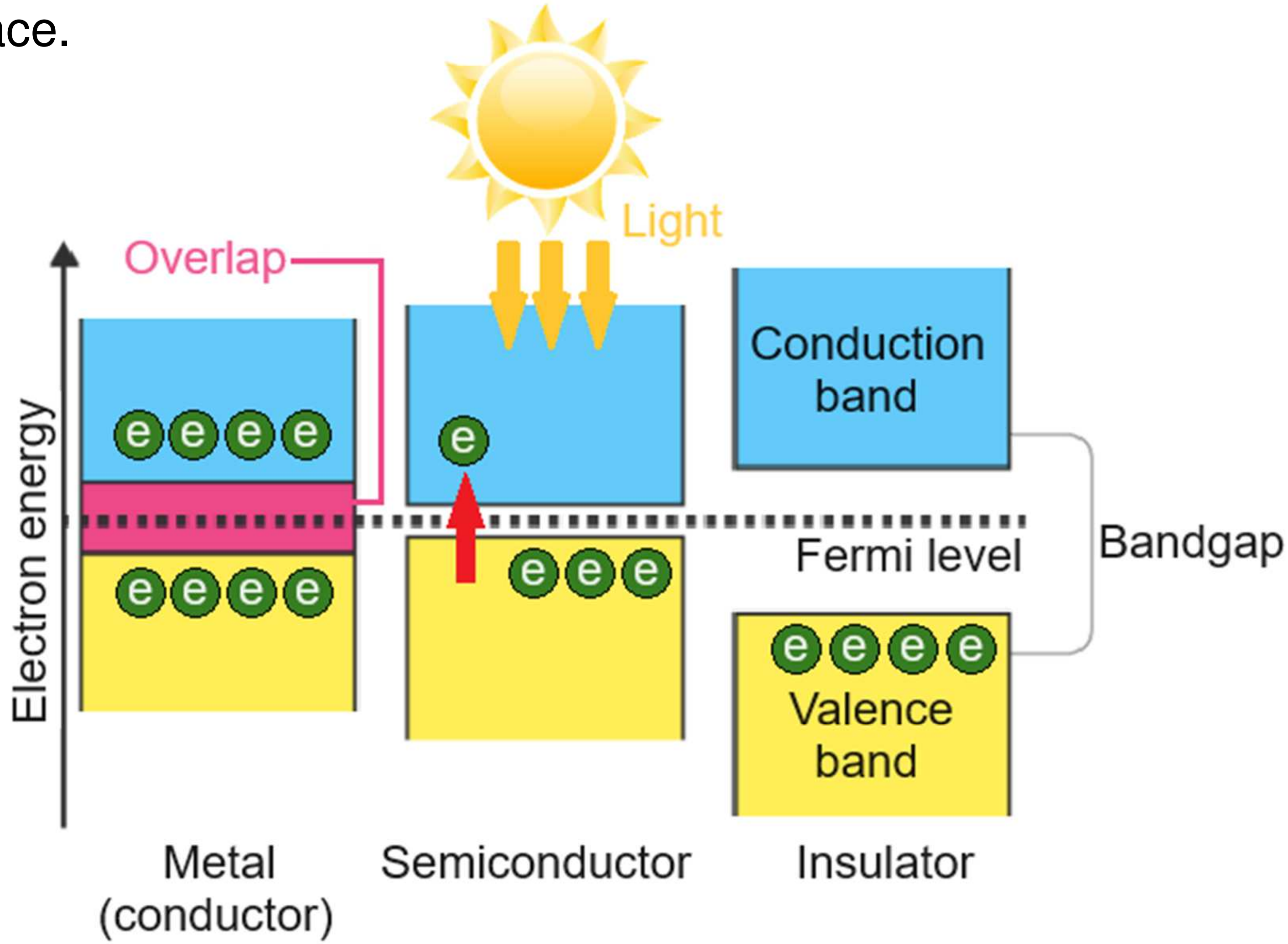
- Definitions:
  - A photovoltaic cell: a large-area semiconductor diode that converts light into electrical energy
  - Photoelectric phenomenon: the release of electrons from the shell of an atom and their subsequent emission due to the absorption of electromagnetic radiation
  - Photovoltaic phenomenon: a form of internal photoelectric phenomenon

    A photon with sufficient energy causes electron transition from the valence to the conduction band in a semiconductor.

    The hole (+) then appears in the original place.

    By connecting a semiconductor into a circuit, electrons travel to the opposite electrode and an electric current occurs.

- A photon with sufficient energy causes electron transition from the valence to the conduction band in a semiconductor. The hole (+) then appears in the original place.



The beginnings of photovoltaics

- The history dates back to the first half of the 19th century!
  - 1839 A. E. Becquerel

    discovered the PV phenomenon
    in a container with electrolyte
    and Pt electrodes

  - 1876 W. G. Adams & R. E. Day

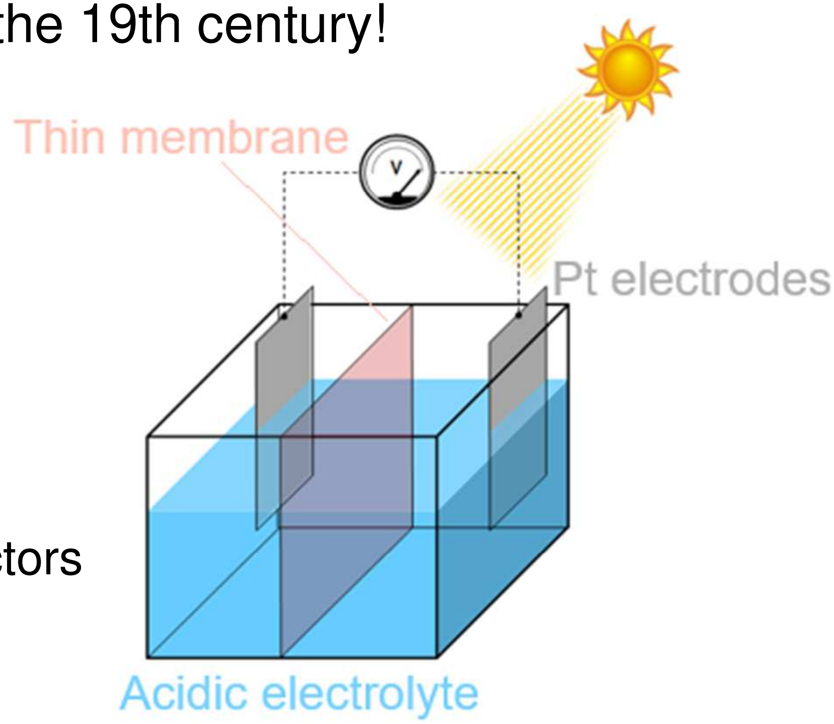
    described the PV phenomenon
    in Se and proposed semiconductors
    as the most suitable approach

  - 1883 C. Fritts

    designed first usable PV cell
    (selenium coated with Au film)

  - 1941 R. Ohl

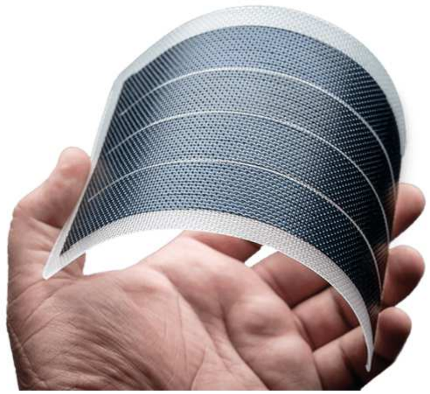
    discovered Si-based PV cell



Basic types of PV cells

- 1st generation
  - ► still the main design in production
  - ► monocrystalline or polycrystalline Si
  - ► older types: BSF (Back Surface Field)
  - ► modern types PERC
    (Passivated Emitter and Rear Cell)

- 2nd generation
  - ► a thin film technology (sputtering, etc.)
  - ► application on multiple types of substrates
  - ► possibility of flexible modules.



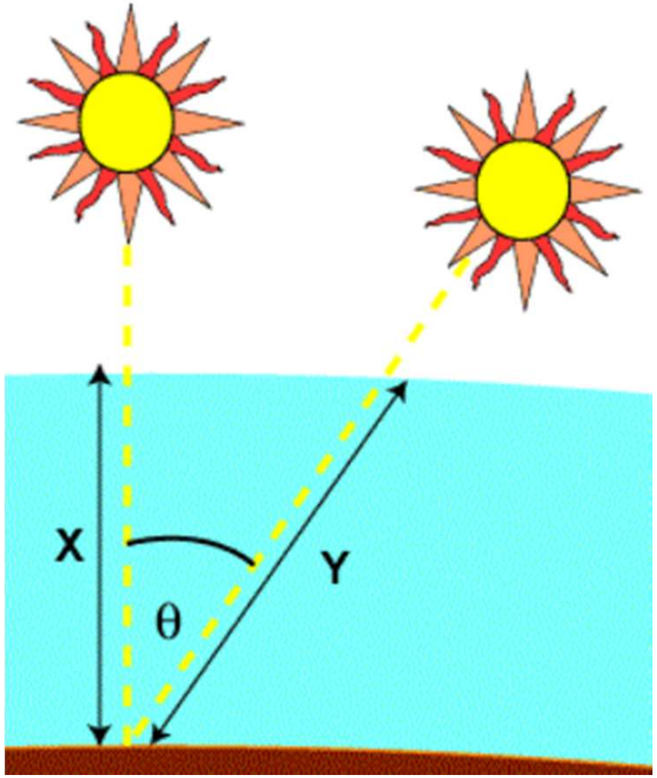
- 3rd generation
  - ► multi-junction cells still under development
  - ► concentrator photovoltaics (CPV)
    radiation concentrated by lenses, etc.

PV cells electric efficiency

- Efficiency is calculated for standard conditions (in reality it is lower)
  - the cell temperature 25 °C
  - energy density exposing the earth's surface 1,000 W m^{-2}
  - solar zenith angle (inclination from the vertical) 48.2°
  - Air Mass (AM) 1.5

AM = the path length which light takes through the atmosphere normalized to the shortest possible path length (when the sun is overhead)

AM quantifies the reduction in the power of light as it passes through the atmosphere and is absorbed by air



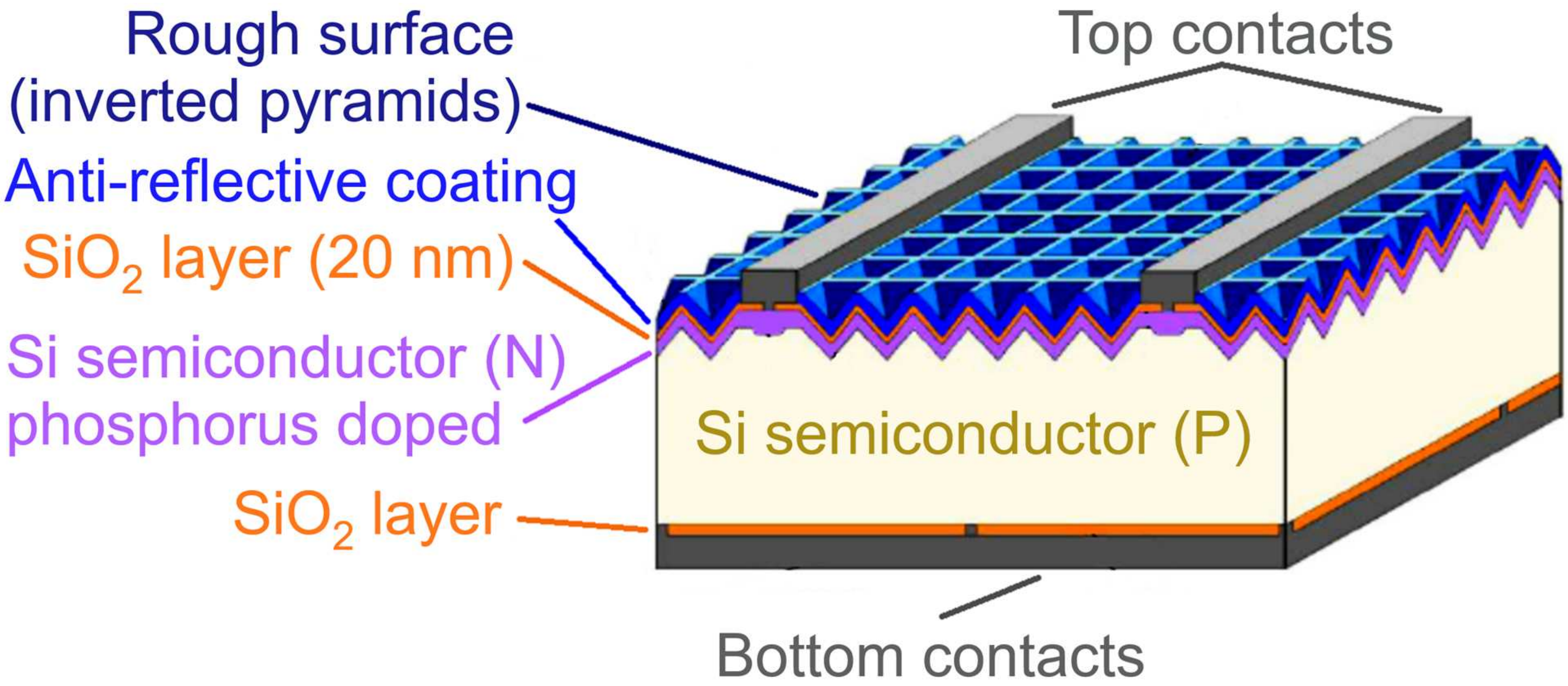
$$AM = \frac{1}{\cos\theta} = \frac{1}{\cos 48.2°} = 1.5$$

PV cells electric efficiency

- Efficiency calculated for standard conditions
- Efficiency varies by the cell type and its quality
- The very first construction from the year 1883
  - 1%
- 1st generation
  - up to 23%
  - 20% typical for standard products on the market
- 2nd generation
  - 8 – 15% only
  - but cheaper production + flexible cells
- 3rd generation
  - >40%

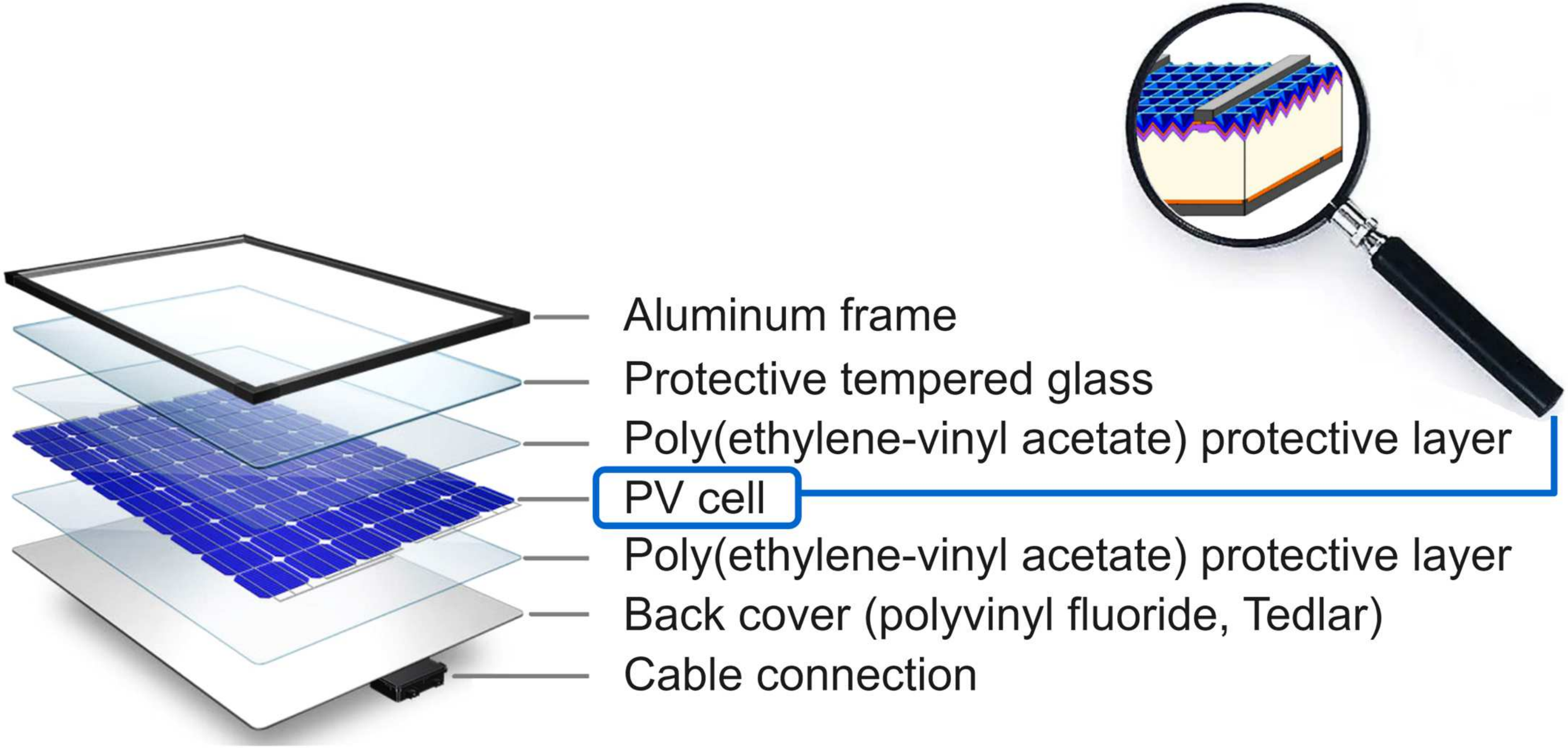
Construction of the most common PV cell

- 1^{st} generation – still dominating
  - ► e^- released in the P semiconductor accumulates in the N semiconductor
  - ► in the past, P semiconductors were doped (e.g. by boron)
  - ► now, the penetration of Al atoms is used in the formation of the bottom Ag-Al contact



The PV cell is the core of the PV panel

- PV cell = the main but not the only part of the PV panel



Photovoltaics: issues requiring development

- The main problems of photovoltaics that still need development:

1. ► Energy-consuming manufacture
2. ► CO_2 emissions during cell production
3. ► Relatively short operating life
4. ► Electrical output dependent on climate zone and season
5. ► Production of electricity at times of lowest consumption (day/night)
6. ► Complicated extinguishing of buildings with photovoltaic panels on the roof
7. ► Very difficult to recycle panels after their end of life

PV cells manufacturing technology

- The production of Si for BSF and PERC cells very energy intensive
  - Step 1: quartz reduced by carbon to SiC and CO
  - Step 2: SiC converted to Si in an electric arc furnace

$$2SiO_2 + 3SiC \xrightarrow{>1{,}835\ °C} 4Si + SiO + 3CO$$

$$SiO + SiC \xrightarrow{>1{,}835\ °C} 2Si + CO$$

  - Environmental problems: high temperatures = high energy consumption
    emissions of CO (toxic gas)
    CO subsequently oxidized in the air:
    $CO + {\bullet}OH \rightarrow CO_2 + {\bullet}H$
    ${\bullet}H + O_2 \rightarrow {\bullet}OOH$ (hydroperoxyl radical)
  - The problem of compliance with ecological standards
    C footprint of PV panel production in China is double that of the EU
    (According to The Department of Energy's Argonne National Laboratory)

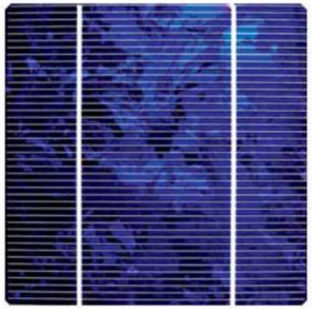
- The production of Si for BSF and PERC cells very energy intensive

► electric arc furnace

► example of the gigafactory:
Wuhan Hongxin
Semiconductor Manufacturing

PV cells manufacturing technology

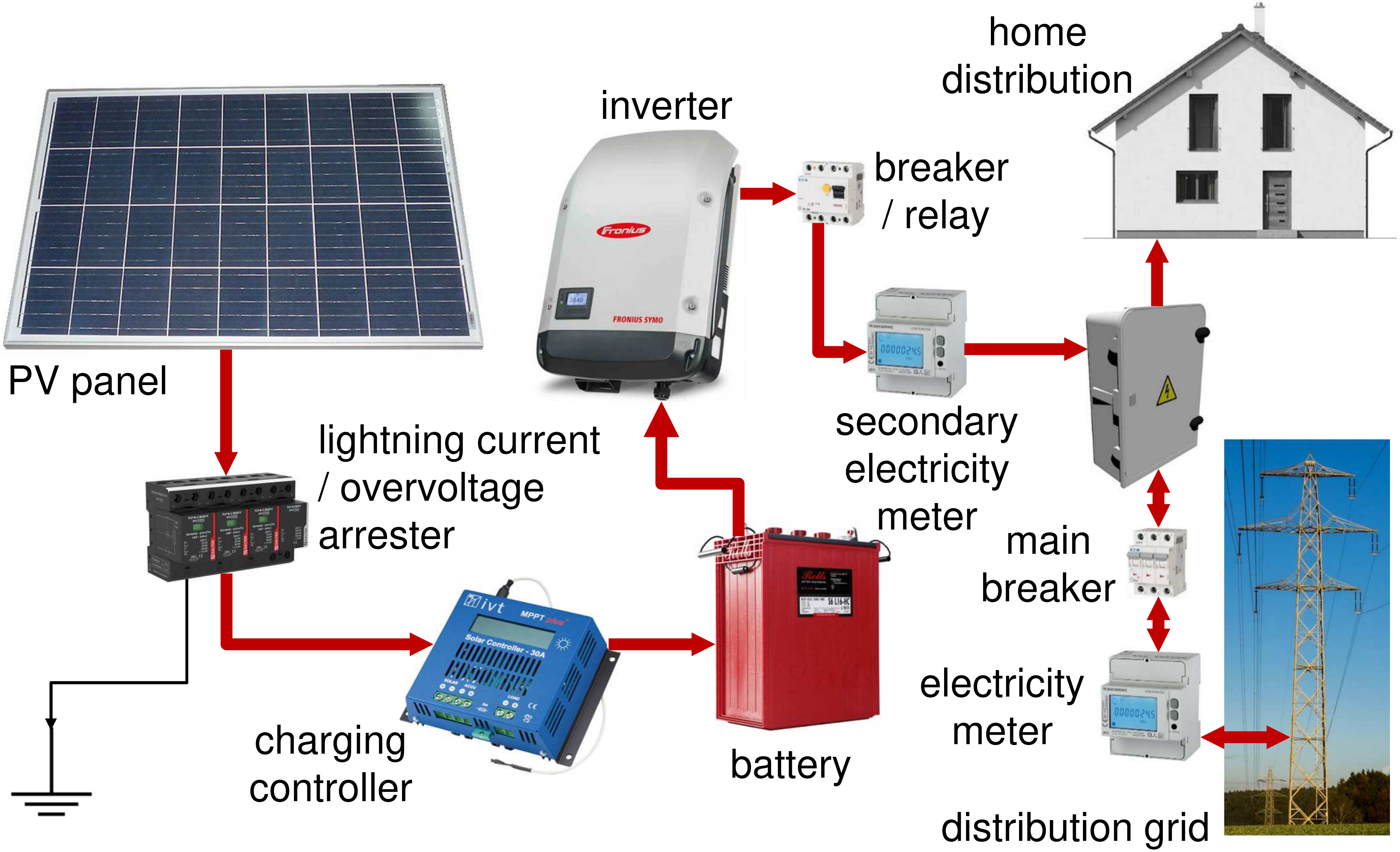
- Example of production of BSF type PV cell
  - Multicrystalline Si ingots are cut to a square cross-section



  - Round monocrystalline ingots are cut to a pseudo-square cross-section

  - Ingots are cut into wafers (on the order of hundreds of μm)
  - A texture is created on the wafers by etching (the wafer becomes opaque and absorbs light better)
  - The wafer is doped with phosphorus (formation of a P-N junction)
  - The wafer is equipped with an anti-reflective layer of nitride (blue color)
  - Screen printing creates metallization on the back and front of the wafer.
  - The cell is sintered (sintered) to form a conductive connection between the metal and the silicon.

A PV power plant is not just a panel

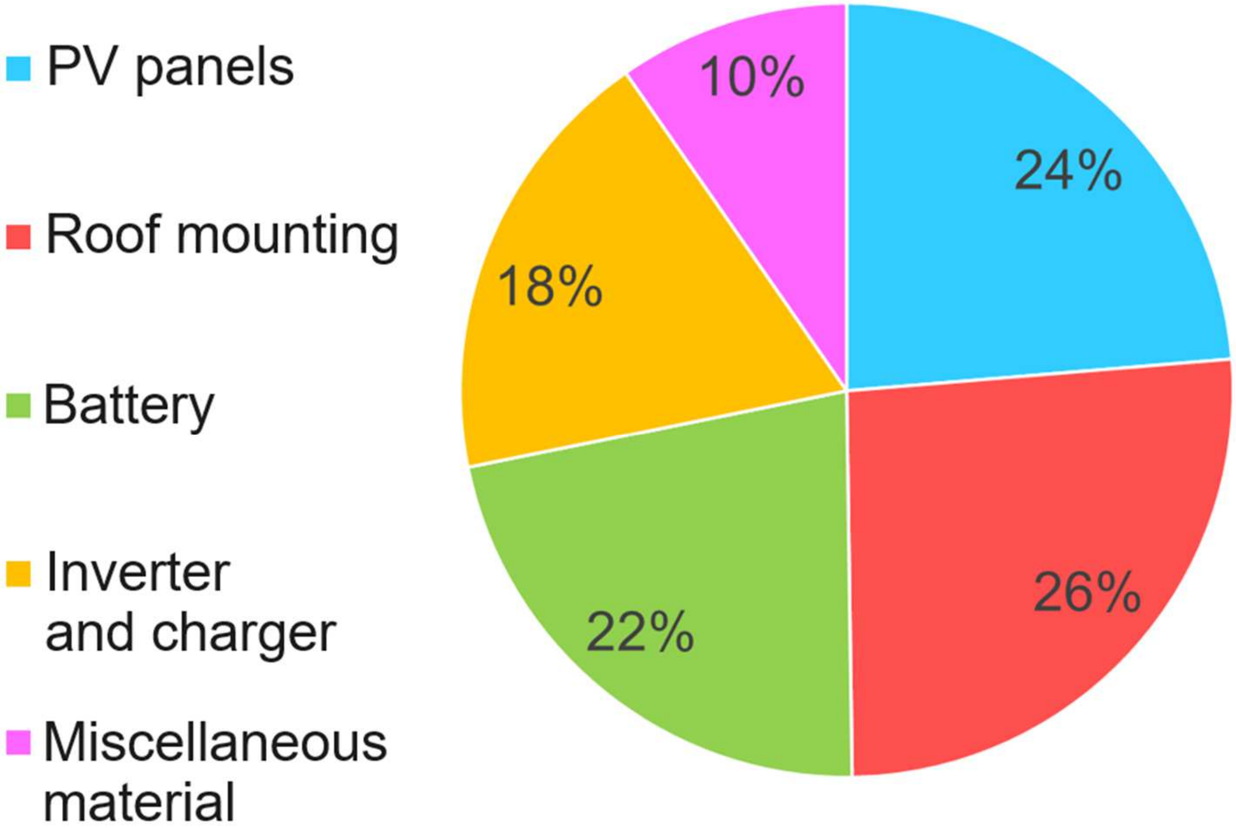


A PV power plant is not just a panel

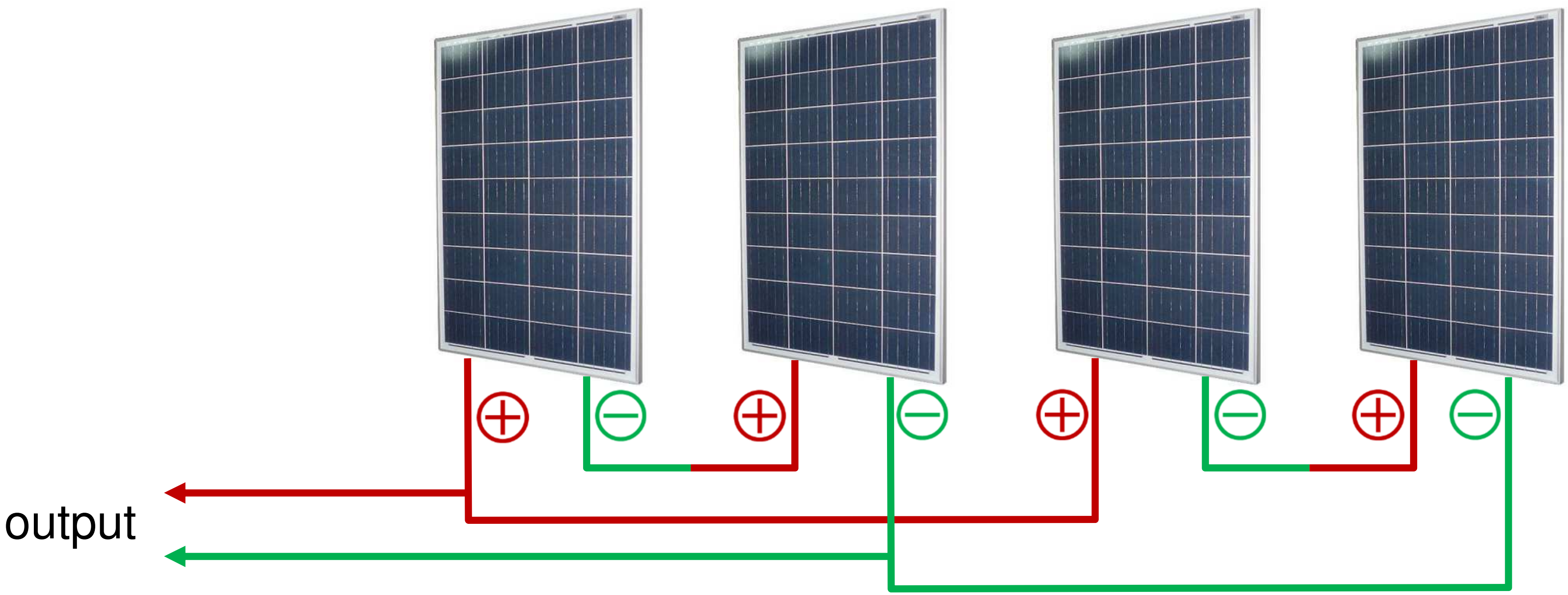
- Installation of very small PV power plants is not advantageous.
  - ► too high costs of material, regulation and electrical installation compared to the low performance.

Example:

a small power plant with a nominal installed power of 2.5 kW



- PV panels on the market give different voltages
- The PV panel always gives DC voltage
  - different nominal voltages: 31.7 V, 41.7 V, 18.3 V ….. etc.
  - series connection - voltage increase
  - parallel connection - current increase



Alternating current versus direct current

- The main advantages of direct current
  - easy recuperation of surpluses (e.g. from PV) back into the grid
  - no synchronization of connected sources (power plants) required
  - little influence on the surroundings of the conductor by induction
  - safer than AC in an accident: it does not cause a heart rhythm disorder
- The main advantages of alternating current
  - the possibility of easy transformation to the desired voltage
  - **great financial savings** in long-distance transmission using high voltage

$$I = \frac{U}{R}, where\ R\ increases\ with\ temperature$$

$$P = U \times I \xrightarrow{therefore} \mathrm{P} = \frac{U^2}{R}$$

  - simpler motors and generators (no commutators required)
  - possibility of frequency regulation (e.g. engine speed)

What can be powered by a 2.5 kW PV?

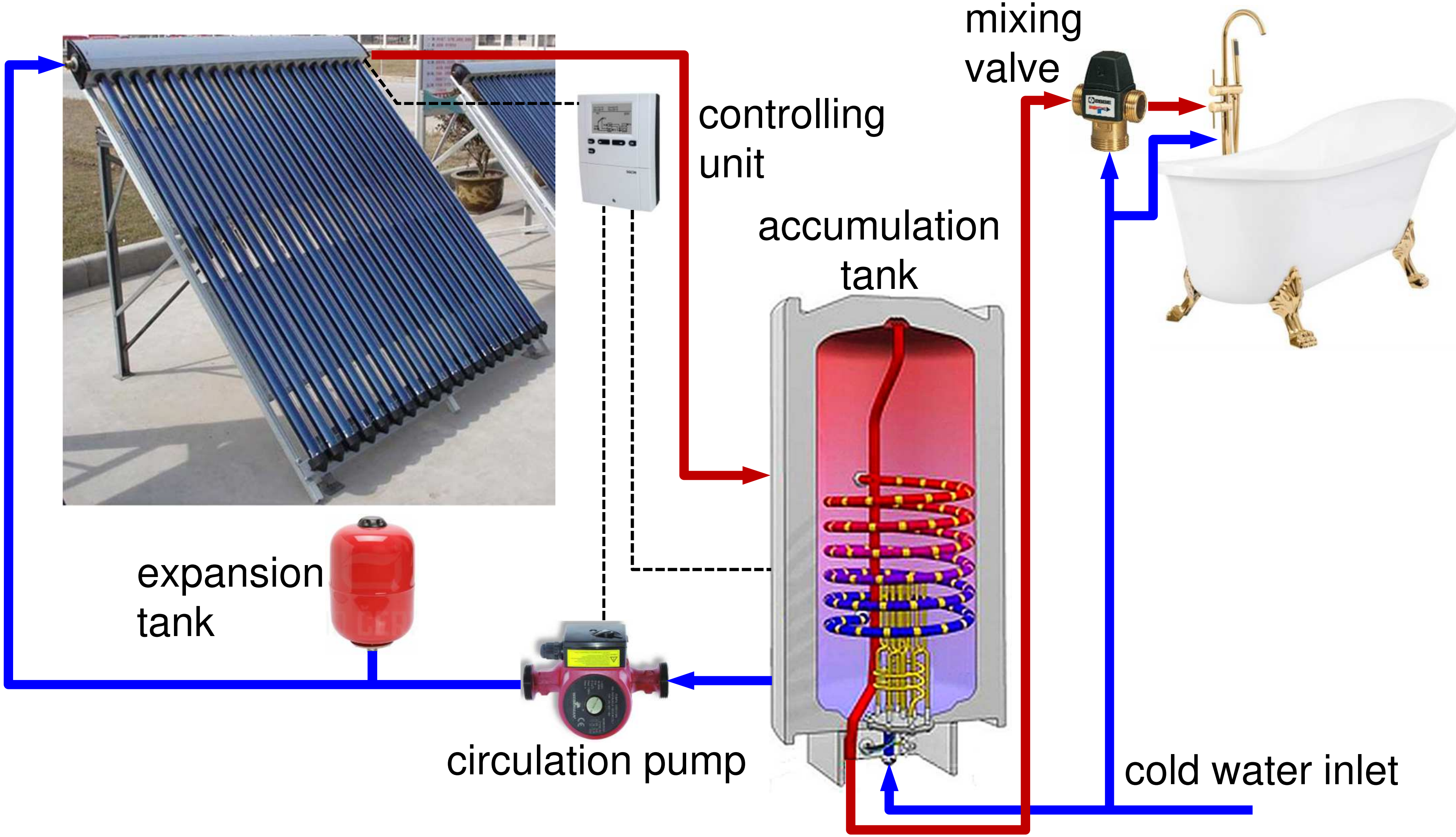
- 2 connection options:
  - ► Island mode: appliances do not draw current from the distribution network
  - ► Phased mode: sale of excess electricity to the grid ⇒ phase synchronization necessary!!!
- What can be connected in island mode (2.5 kW / no battery):
  - ► Ideal conditions: noon, temperature 25 °C, cloudless sky

    1 dishwasher (power 2.4 kW)

  - ► Common conditions: cumulus clouds, spring-autumn 9:00 a.m. - 6:00 p.m

    1 teapot (power input 1.5 kW)

- Example: a circuit for heating domestic water:



Parameters of solar collectors

- Efficiency of collectors for the domestic hot water preparation
  - ► average for quality collectors 50 – 60%
- Collectors performance (south side, slope 30 – 50°)
  - ► absorption of the solar spectrum >93%
  - ► heat gain ca. 350 kWh m^{-2} $year^{-1}$
- Lifespan
  - ► tested according to European standard EN 12975-2
  - ► for quality collectors 25 to 30 years
- Capital costs compared to PV
  - ► a technically simpler device
  - ► with the same power by tens of percent lower than for PV

Solar collectors distribution

- Multiple technical solutions

cover glass
- none
- single-layer
- multi-layer
- structure

collector design
- flat
- tube
- concentration

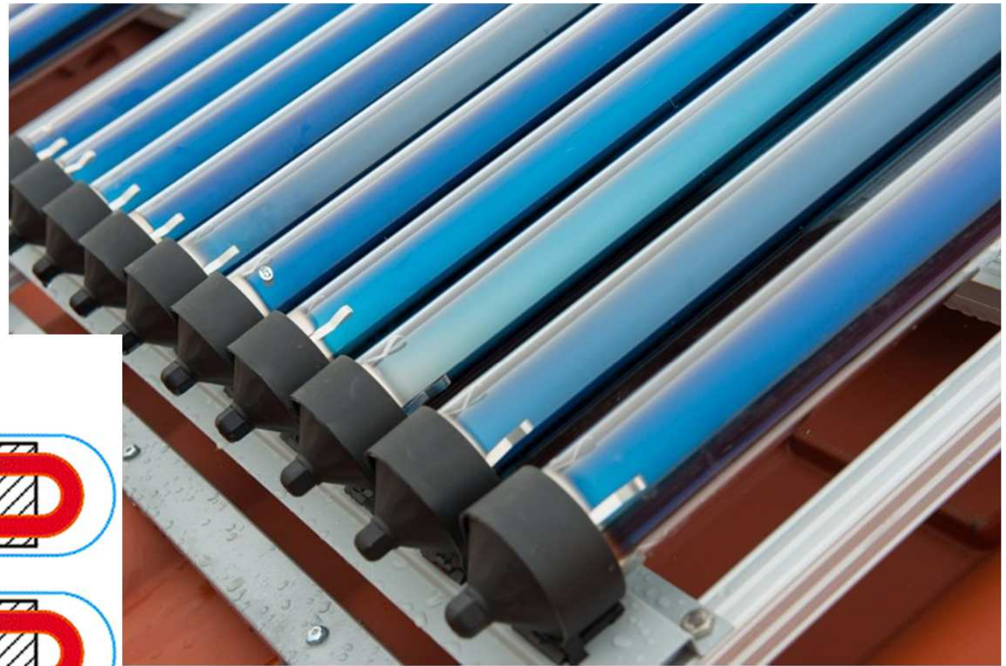
heat transfer medium
- liquid
- air

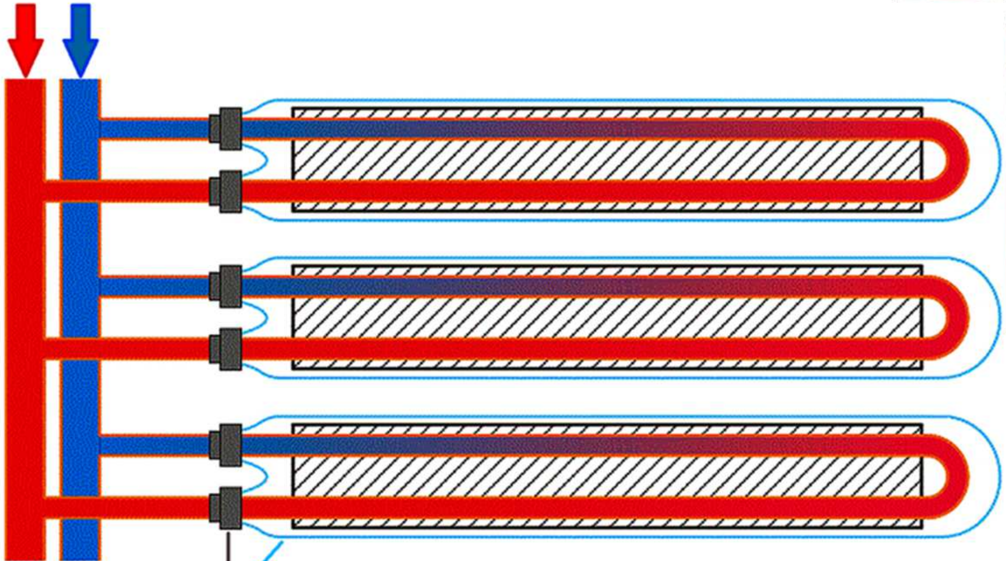
filling pressure
- atmospheric
- vacuum

radiation absorber
- plastic
- metal non-selective
- metal selective
- accumulative

Vacuum solar collector

- Technical solution
  - ► antifreeze liquid circulating in Cu pipes
  - ► Cu pipes inside vacuum tubes





an insert with a light-selective surface placed inside the vacuum tubes.

- Advantages and disadvantages compared to a vacuum system
  - generally more reliable than vacuum
  - lower efficiency in the winter months
  - conversely, higher glass thickness (3.2 mm and more) = better protection against hail
  - lower weight

References (figures)

1. https://byjus.com/jee/conduction-band/
2. www.ennomotive.com/future-of-solar-energy
3. https://oenergetice.cz/slug/polovodice-fotovoltaicke-clanky-krystalickeho-kremiku-tenkovrstve-clanky
4. https://www.pveducation.org/pvcdrom/properties-of-sunlight/air-mass
5. www.cez.cz/edee/content/microsites/solarni/f8.htm
6. www.hqline.com/fotovoltaicke-panely
7. www.fvesystemy.cz/Terminologie-a5_0.htm
8. https://m.made-in-china.com/product/Submerged-Arc-Furnace-for-Industrial-Silicon-Melting-Furnace-8000kVA-720892832.html
9. www.djsarchitecture.cz/fotovoltaika-pro-rodinny-dum
10. www.solarniexperti.cz/solarni-systemy/fotovoltaika
11. www.i4wifi.cz/cs/211193-gwl-power-gridfree-1000
12. https://www.cronimo.cz/solarni-trubice

References (figures)

13. https://profesis.ckait.cz/dokumenty-ckait/mp-1-6/mp-1-6-11

14. https://solarni-ohrev-vody.cz/clanky/srovnani-vakuovych-a-deskovych-kolektoru