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Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

NEST
NETWORK FOR ENERGY SUSTAINABLE TRANSITION

ORDINE DEGLI INGEGNERI
DELLA PROVINCIA DI PALERMO

NEST
NETWORK FOR ENERGY SUSTAINABLE TRANSITION

Celle solari e relativa evoluzione

Innovazione tecnologica per l'uso efficiente dell'energia solare: stato dell'arte e Progetto NEST

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Università degli Studi di Palermo - 11/04/2025

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"Extended Partnership" for the theme "Energy Scenarios of the Future, line 2a: Green Energies of the Future"

from my gym, 27/04/2024, 12:37

from my office@UniPA, 02/05/2024, 14:15

Energy Transition

From fossil fuels towards the dream of 100% of clean energy production.

Fossil Fuels

Energy Transition →

Clean and Renewable Sources

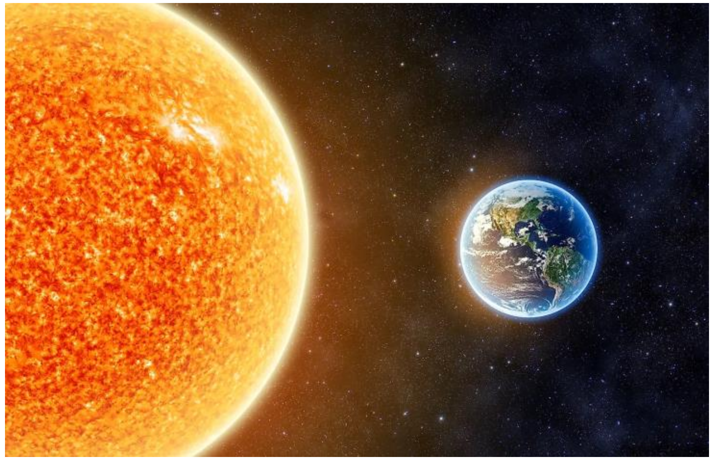
The EU has agreed on the ambitious goal of reducing final energy consumption by at least 12 %:

- “Green Buildings” with 0 emission within 2050.
- Electric cars will replace the petrol cars within 2035.
- More environmental and energy regulations for industries.

Spoke 1: Solar Energy

Sunlight

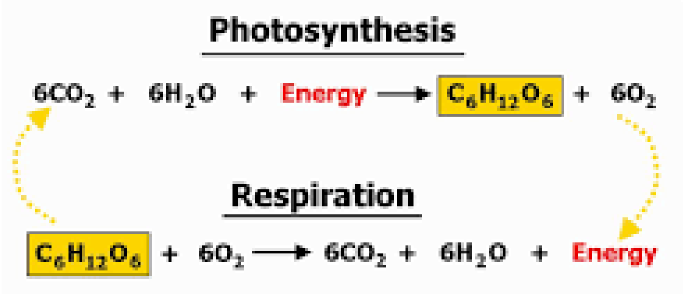
clean and inexhaustible source of energy.



Photosynthesis

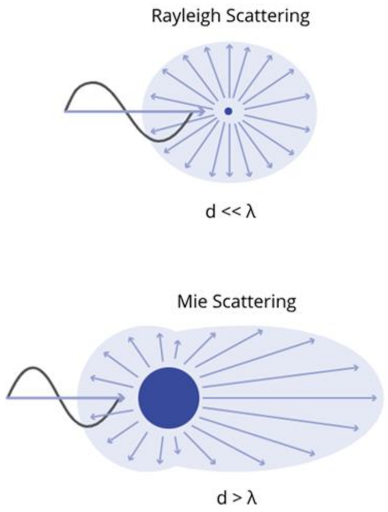
fundamental process for Life on the Earth.

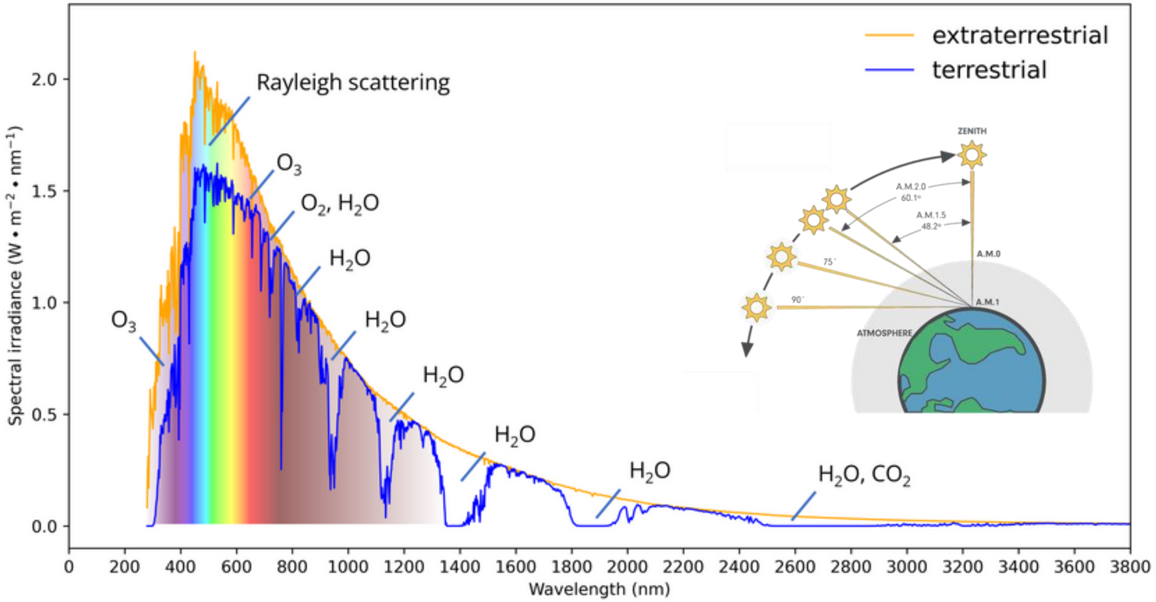
- The Sun provides us in 1 hour with the energy humans consume in a **whole year!** That is 170 x 10^{15} Wh.
- Readily available for technological energy devices: **solar cells**.



The Sunlight

Renewable, inexhaustible, clean source of energy.





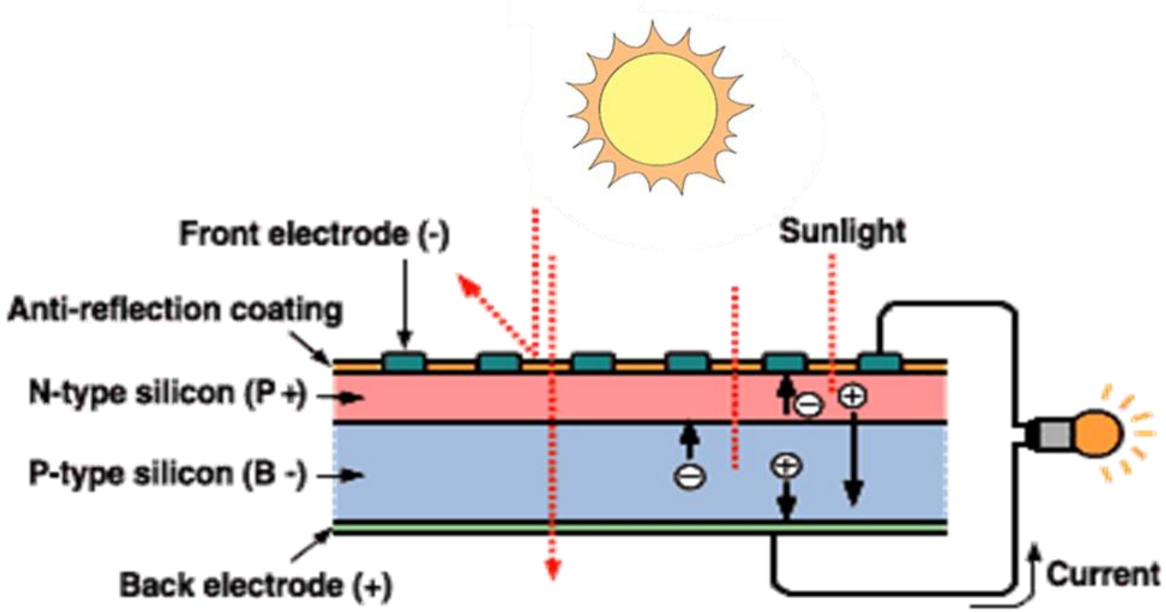
www.ossila.com/the-solar-spectrum.

UV 250 to 400 nm, or 5 to 3 eV **Vis 400 to 800 nm, or 3 to 1.8 eV** **IR 800 to 3500 nm, or 1.8 to 0.35 eV**

On the Earth's surface the sunlight intensity depends on Sun distance, rays angle, weather, air pollution.
Absorption by atmosphere molecules and **scattering** processes affect the Sun spectrum at the ground level.

Solar Cells

Devices for light conversion into electricity



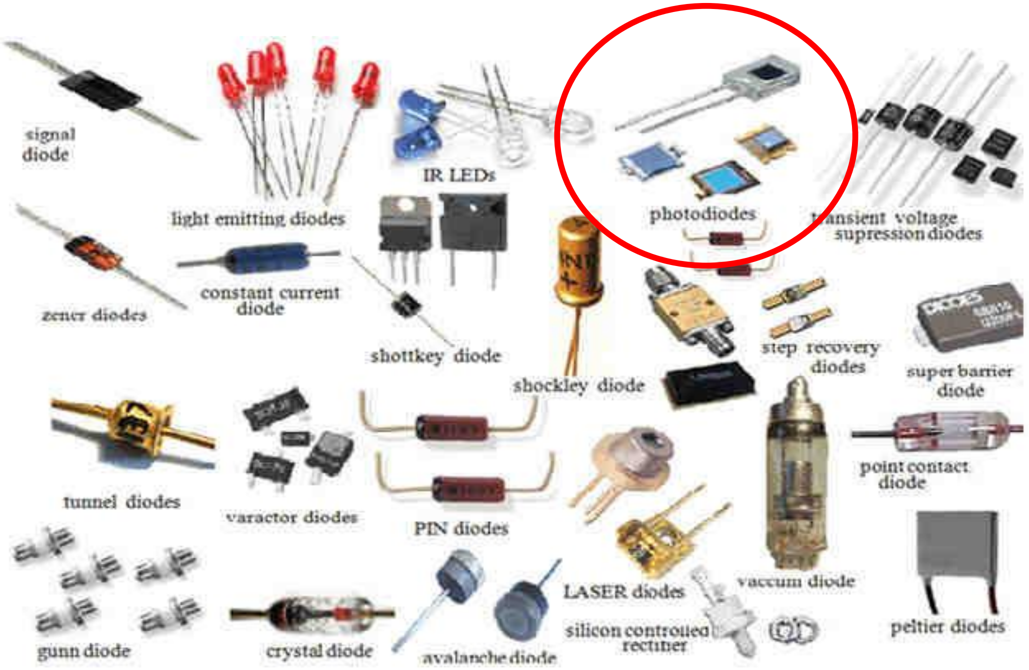
1. The **PN Junction** plays a fundamental role in solar cells.

2. Upon shining light, the **Generation process** occurs at the PN junction, then the charge carriers migrate towards the electrodes.

3. Light can be converted into **electricity**.

Important to notice that combinations of materials properly chosen can act as a PN Juction without needing of extrinsic doping processes: new generation solar cells, e.g. TiO2 can be used as n-type material in perovskite solar cells.

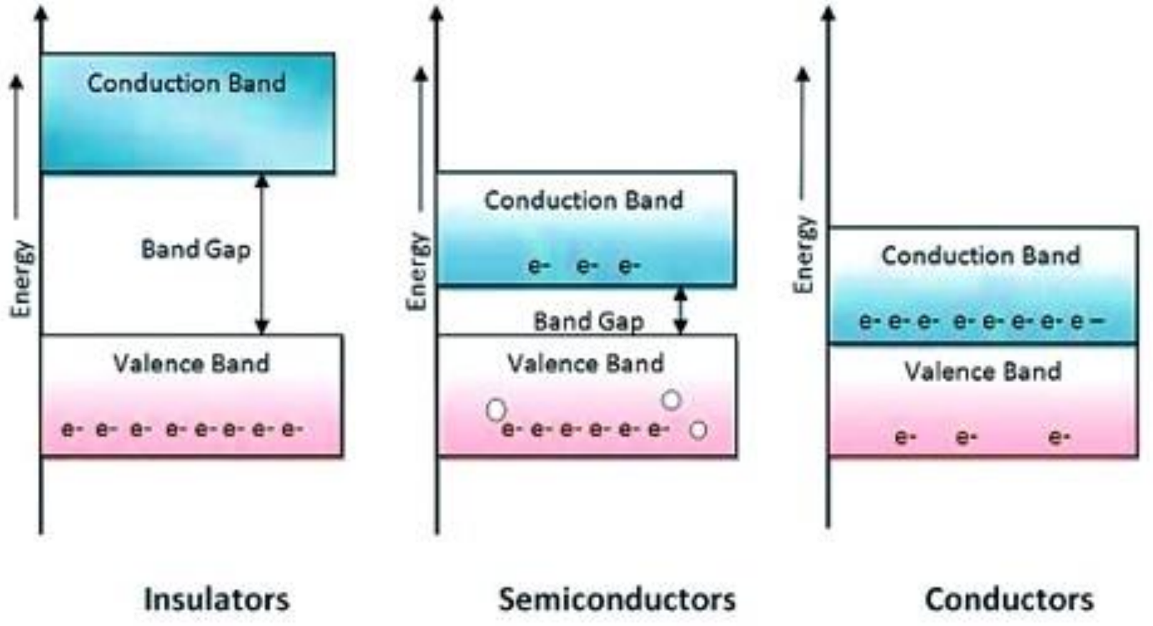
Optoelectronics

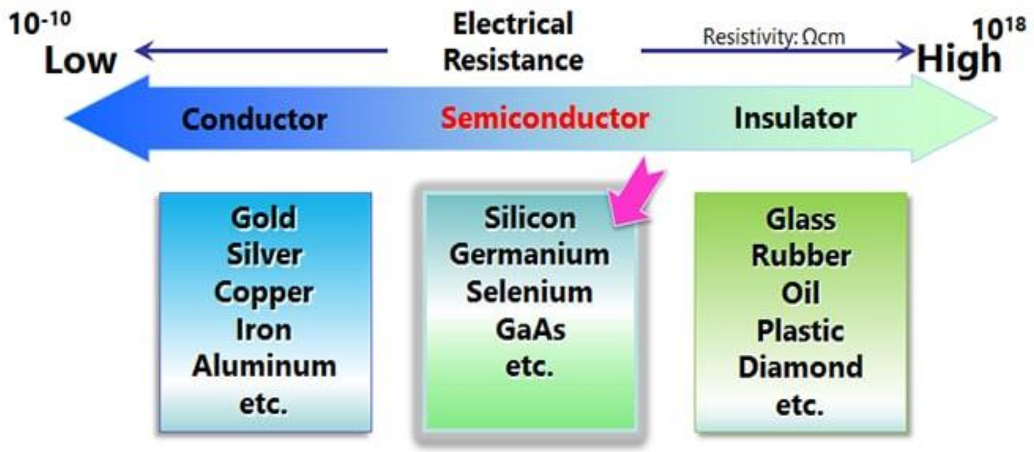


The current technology is based on the use of **semiconducting materials**.

- Semiconductors play a fundamental role in **Optoelectronics**: "branch of technology concerned with the combined use of electronics and light".
- The characteristics of semiconductors allowed for the development of **solar cells**, and other functional **diodes**.

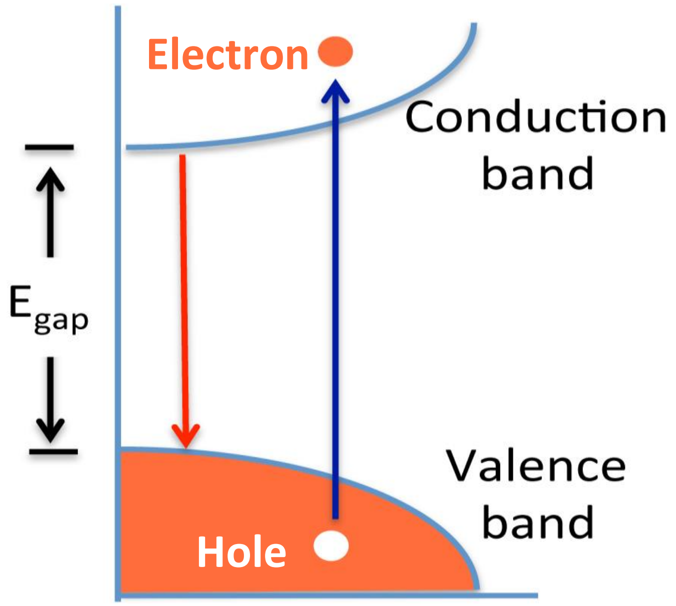
Semiconductors

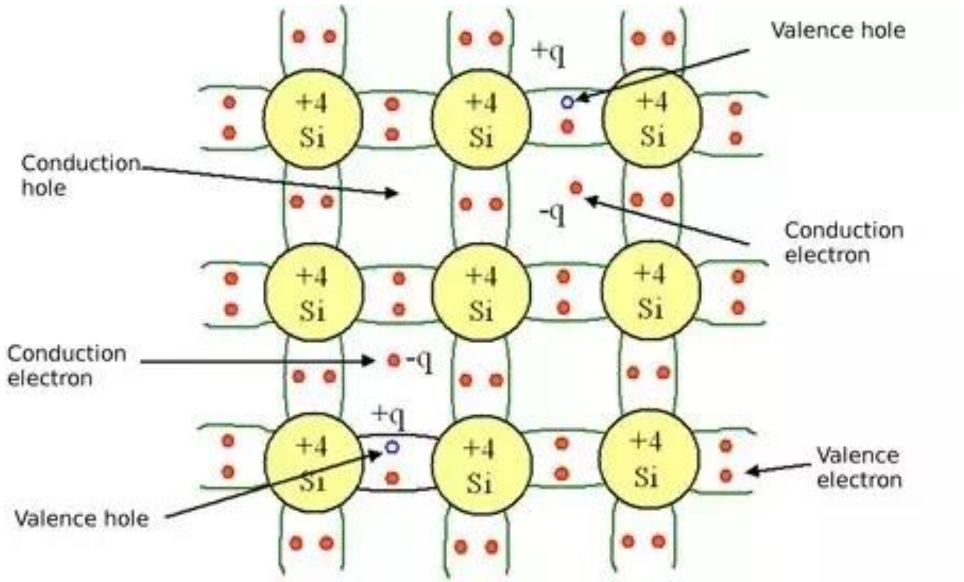




- The properties of semiconductors depend on their **electronic structure**: the larger the **band gap** the lower the electrical conductivity of solid materials.
- Electronic properties of semiconductors can be properly tuned by **doping**.
- The **photovoltaic effect** in semiconducting materials allowed for solar cells development.

Charge Carriers in Semiconductors

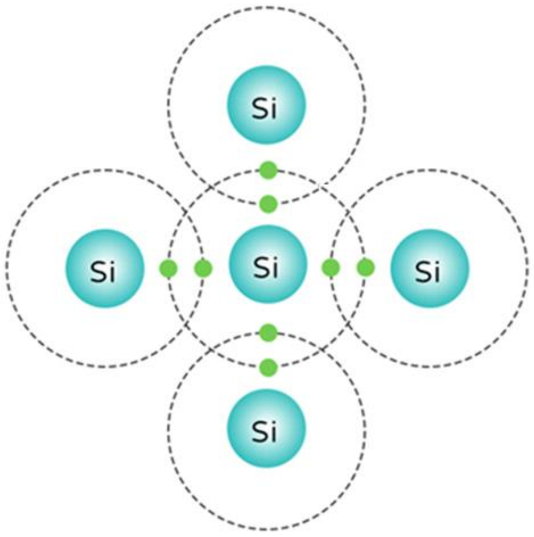




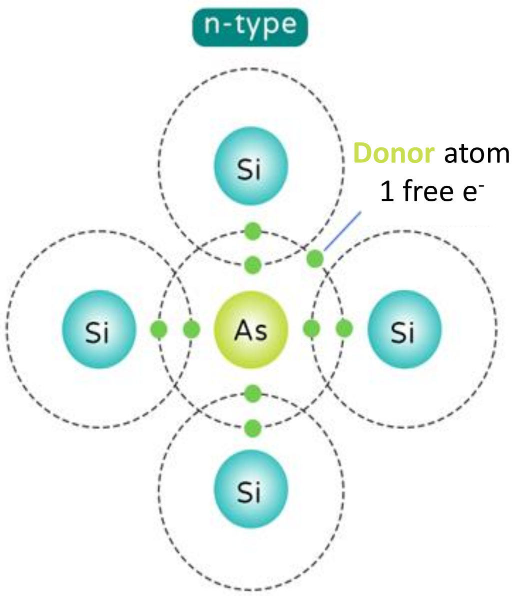
- In **solids**, the charge carriers are represented by excited **electrons** and **holes**, obtained by the excitation process
- Charge carriers can either relax by losing energy, e.g. light emission, thermalization, etc. also concurrently.
- Excited electrons in the conduction band and holes in the valence can be used to obtain a **current**.

Doping

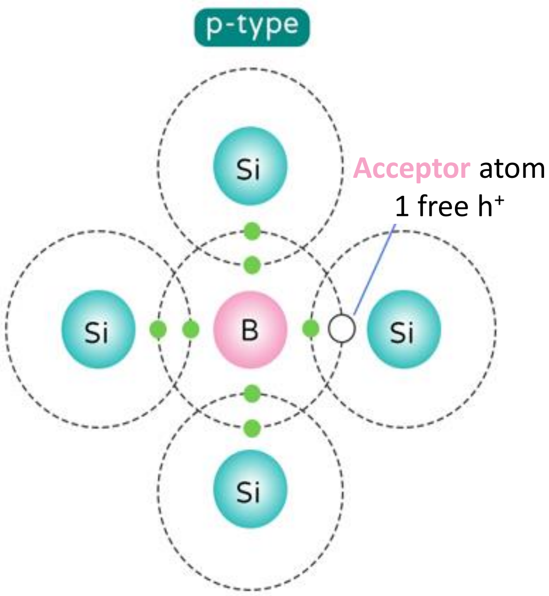
Doping: modifying materials in **chemical** or **physicochemical** way to manipulate their electronic features.



Equal number of electrons and holes



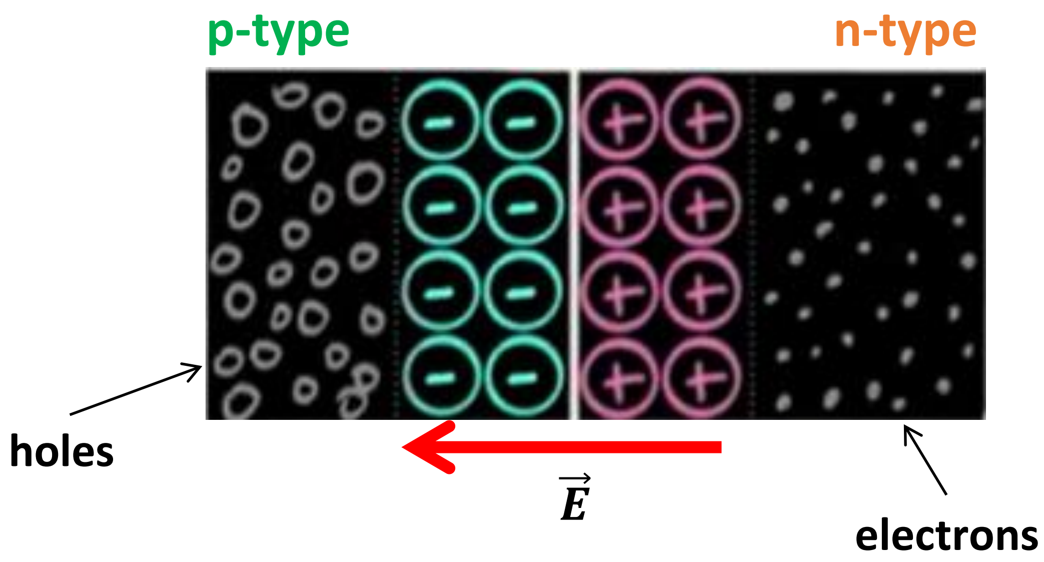
Higher number of free **electrons**

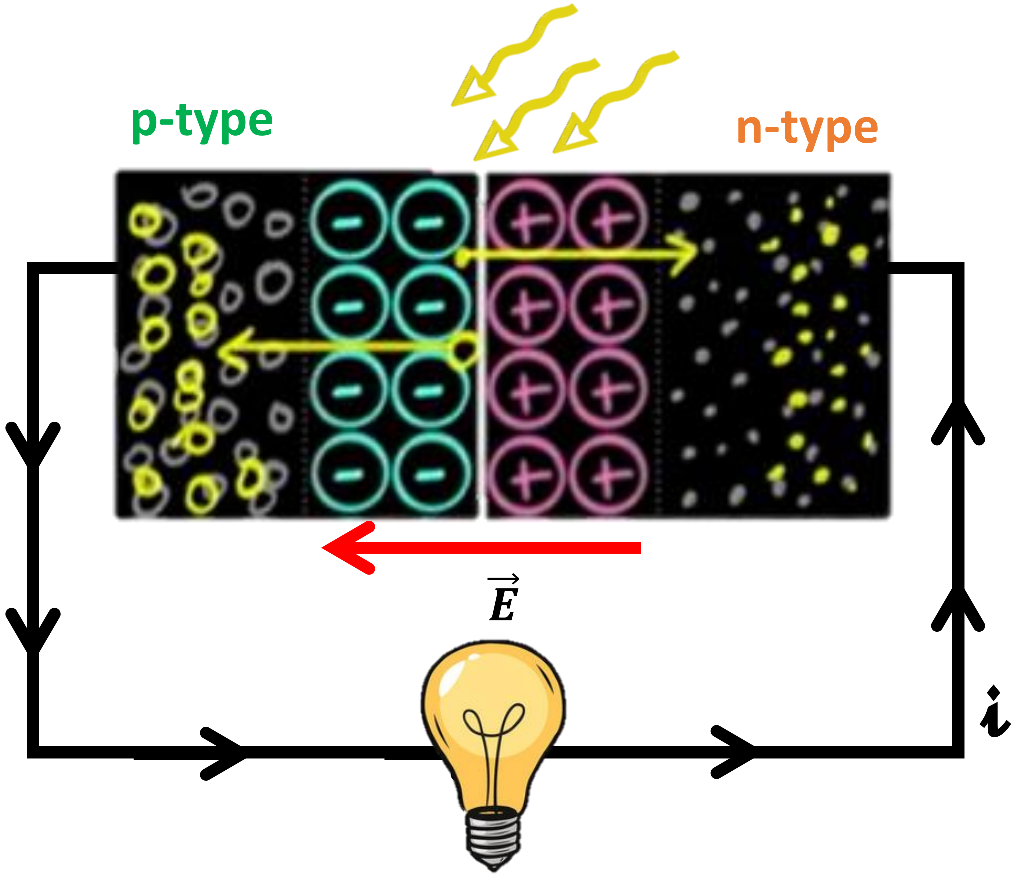


Higher number of free **holes**

The Photovoltaic Effect

The PhotoVoltaic **Effect** consists in generating an internal voltage difference by shining light on a material.



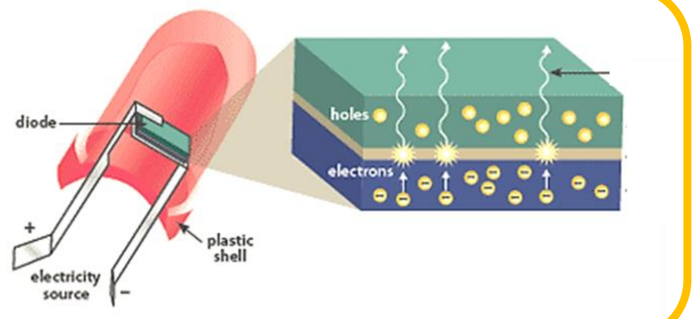


By means of the PhotoVoltaic **Effect** light can be exploited to get **Electricity**!

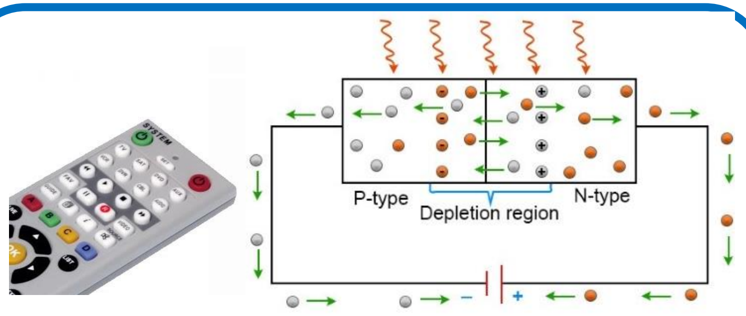
PN-Junction

Fundamental component for most of the Optoelectronic devices.

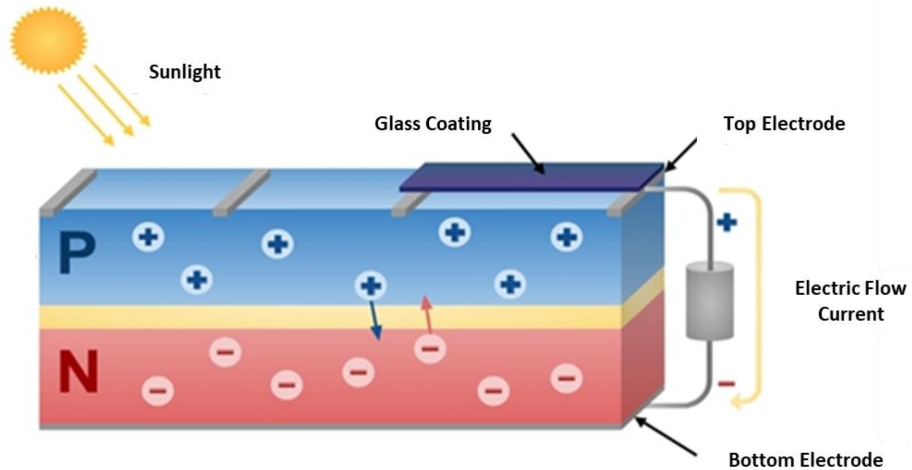
Light Emitting Diode



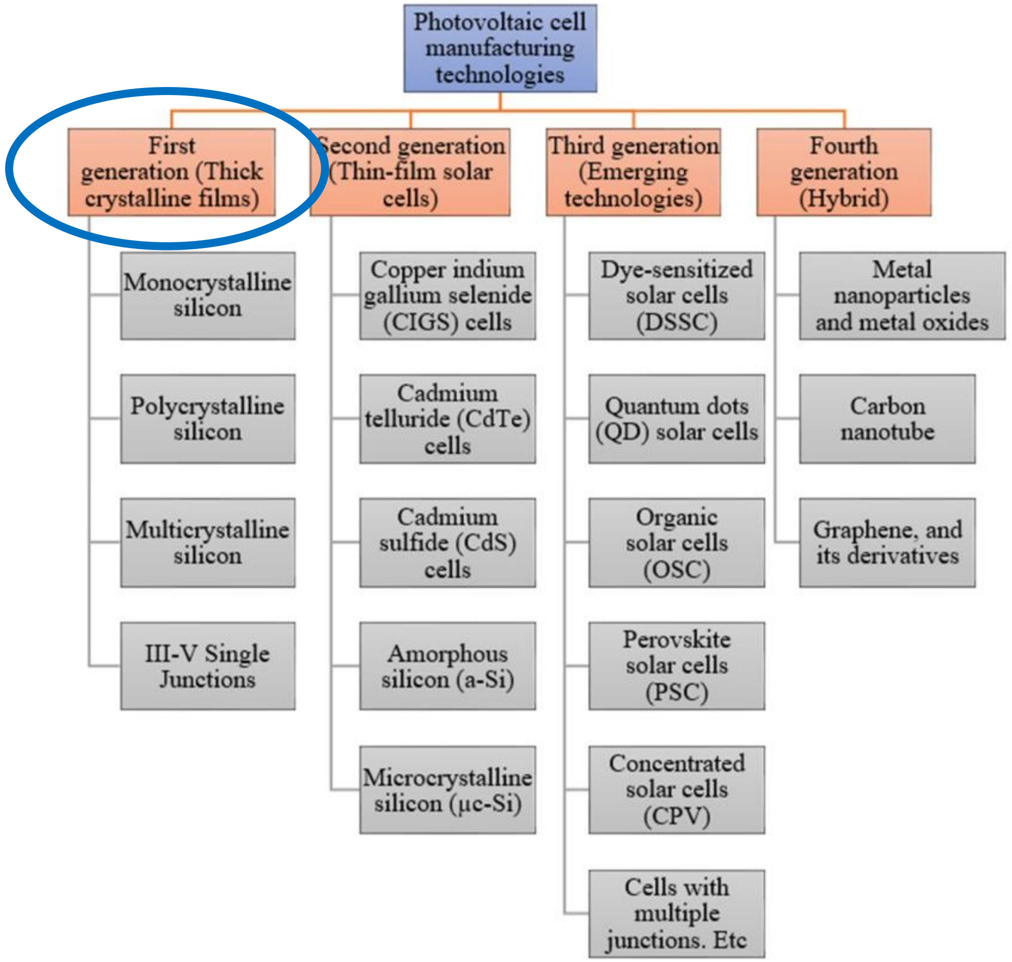
Photodiode



Solar Cells



Solar Cells Generations



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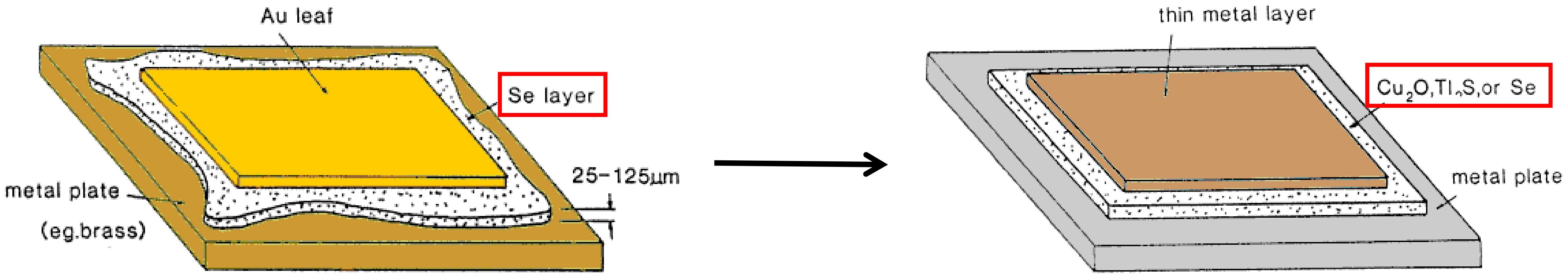
First Photovoltaic Devices

In 1883, American inventor Charles Fritts made the first solar cells from **selenium**.



www.pveducation.org

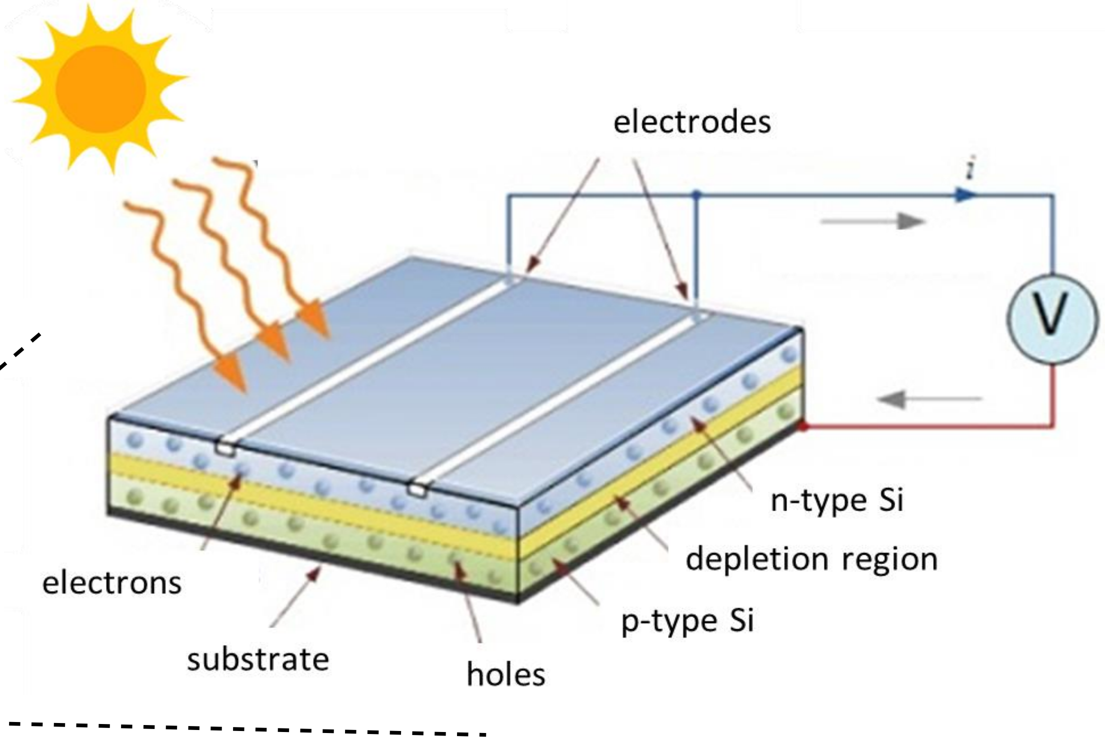
Main Characteristics

By compressing molten selenium between plates of metals, Fritts prepared the first solar cell, as large as **30 cm^2 in area**.

The first solar devices were developed without any **charge transport layers** inbetween the active phase and the metallic contacts.

Commercial Silicon-based Solar Cells

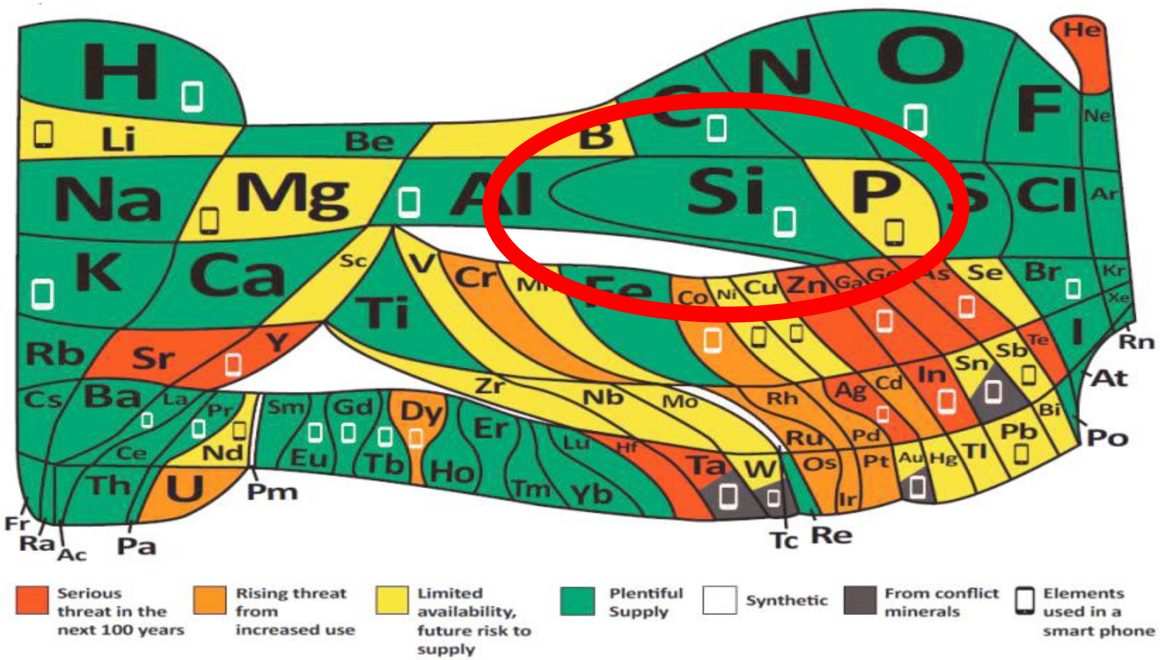
A rough mean of the energy of sunlight photons is 1.5 eV



Why is Silicon so successful?

Silicon for Solar Cells

Properties of silicon for technological applications.



www.euchems.eu/euchems-periodic-table

Availability of elements is fundamental for future technology design

10^{22} atom/cm^3

$n_i \sim 10^{10}$/cm^3

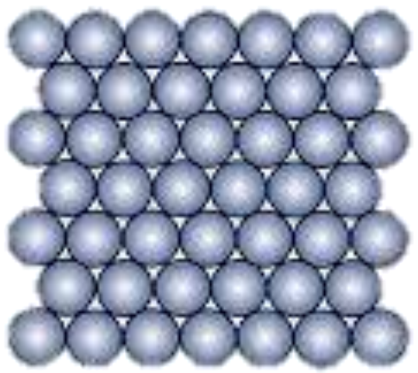
10^{12} atoms for 1 free e^- and 1 h^+

For comparison in a typical conductor, such as copper, 1 atom contributes with 1 free e^- and 1 h^+

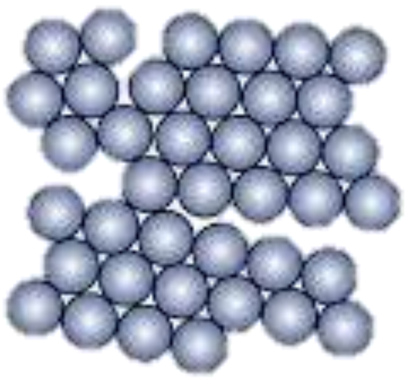
Common semiconductors band gaps (eV):

Ge	Si	GaAs	GaP	GaN
0.7	1.1	1.4	2.3	3.4

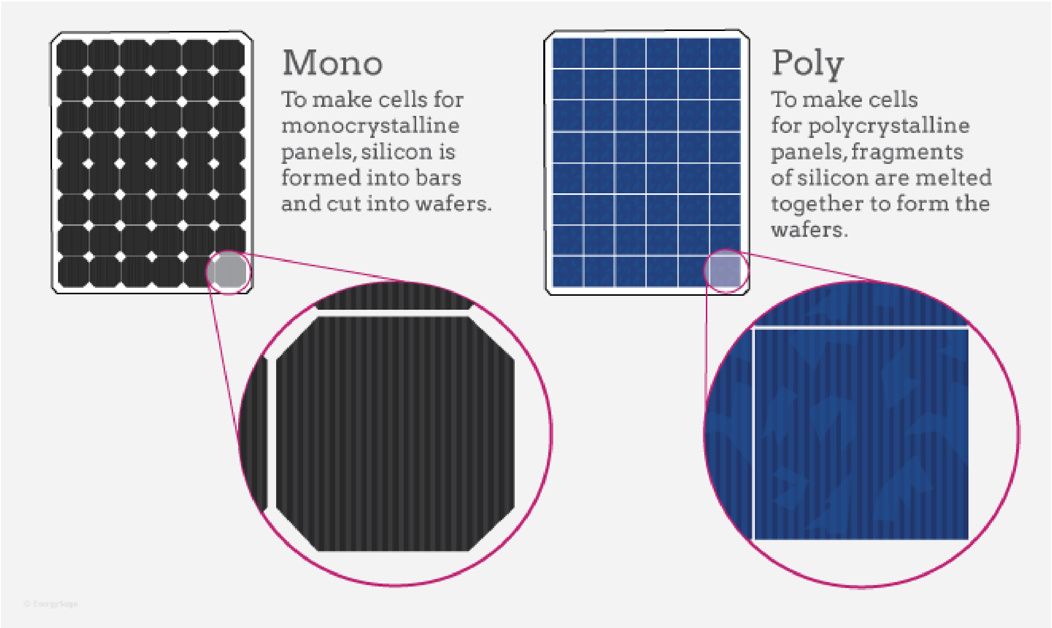
Monocrystalline and Polycrystalline Silicon



Monocrystalline



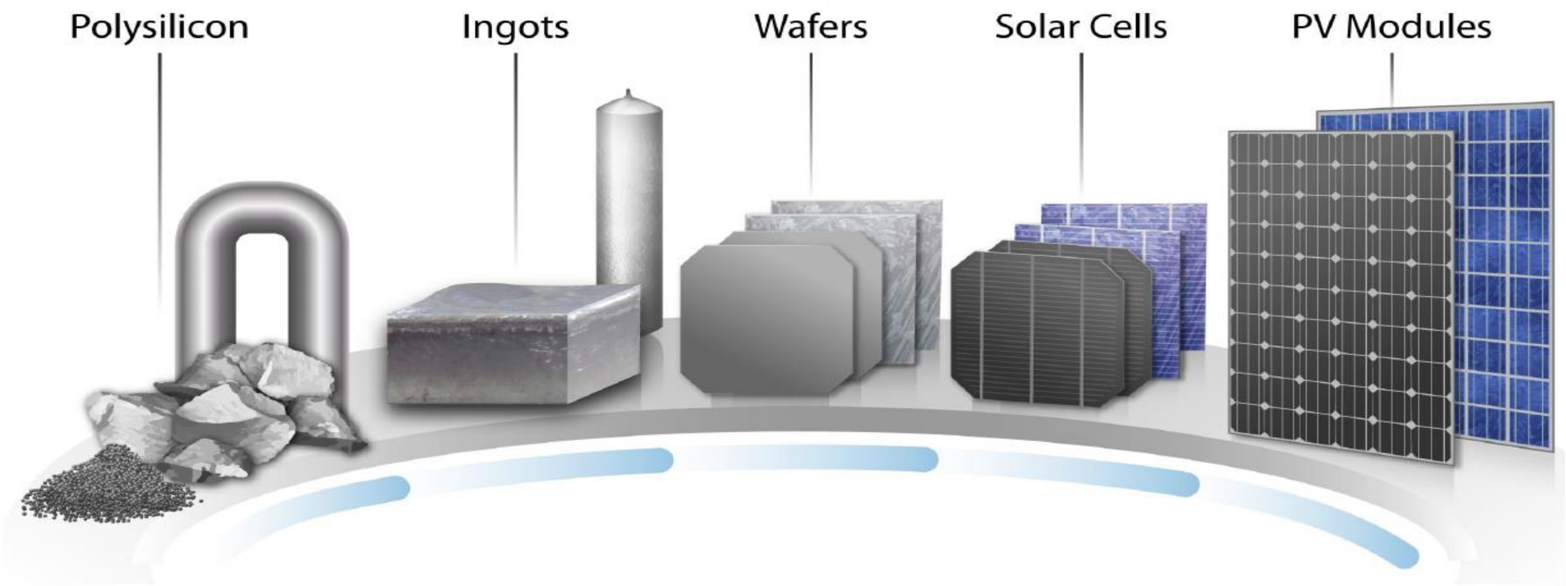
Polycrystalline



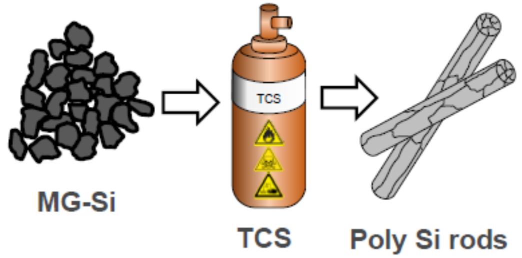
www.ases.org/monocrystalline-vs-polycrystalline-solar-panels/

Silicon based solar cells are the first-generation solar cells normally produced on silicon wafers. They can be divided into crystalline silicon (c-Si) solar cells and thin film silicon solar cells according to silicon wafers' thickness

Monocrystalline Wafers



1)



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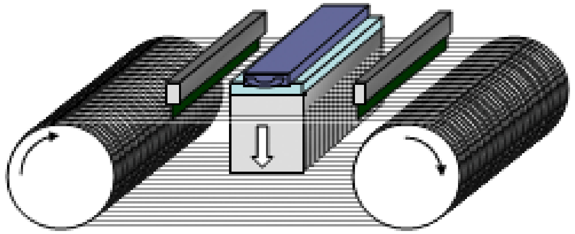
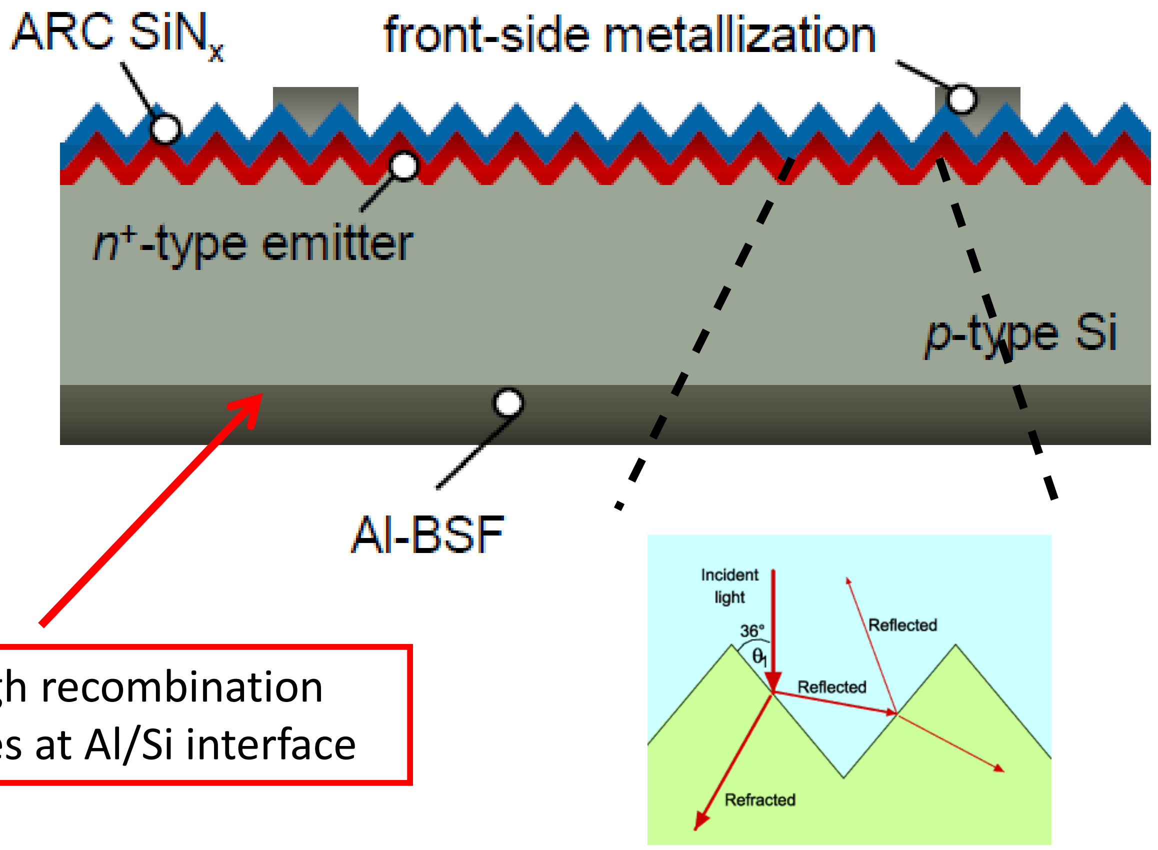
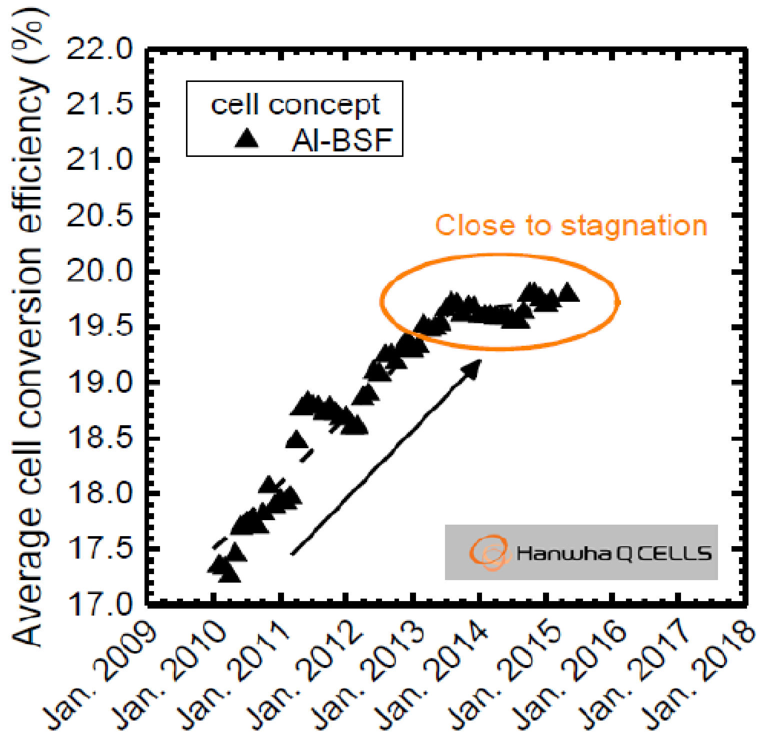
3)



The first mass-produced Si cell: Al back-surface field (Al-BSF)

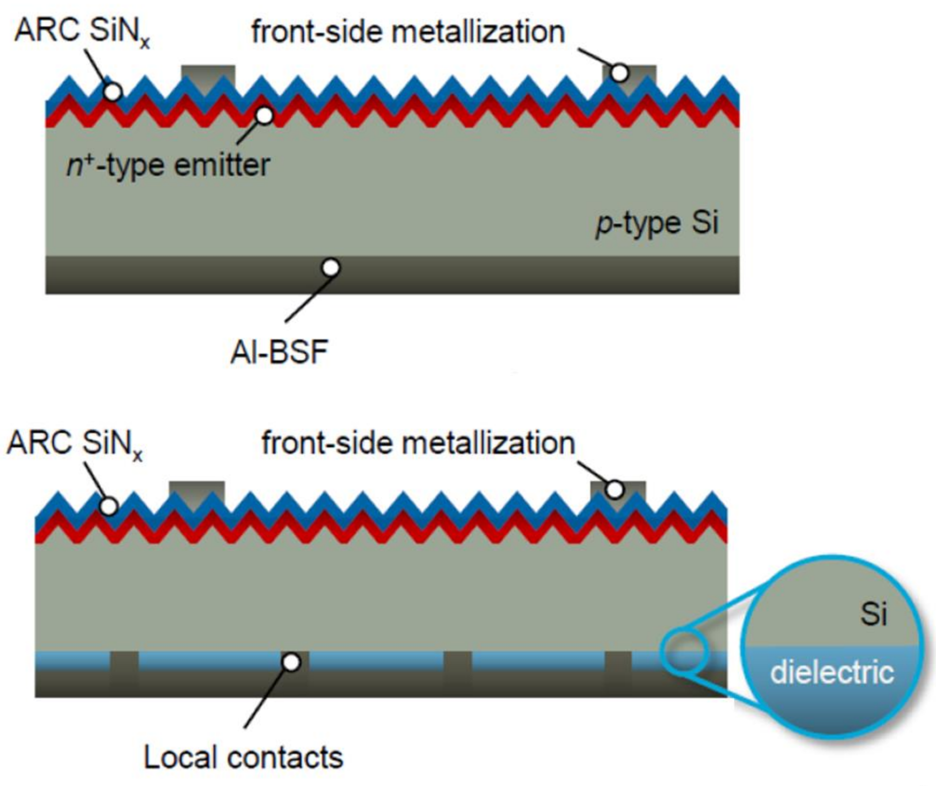


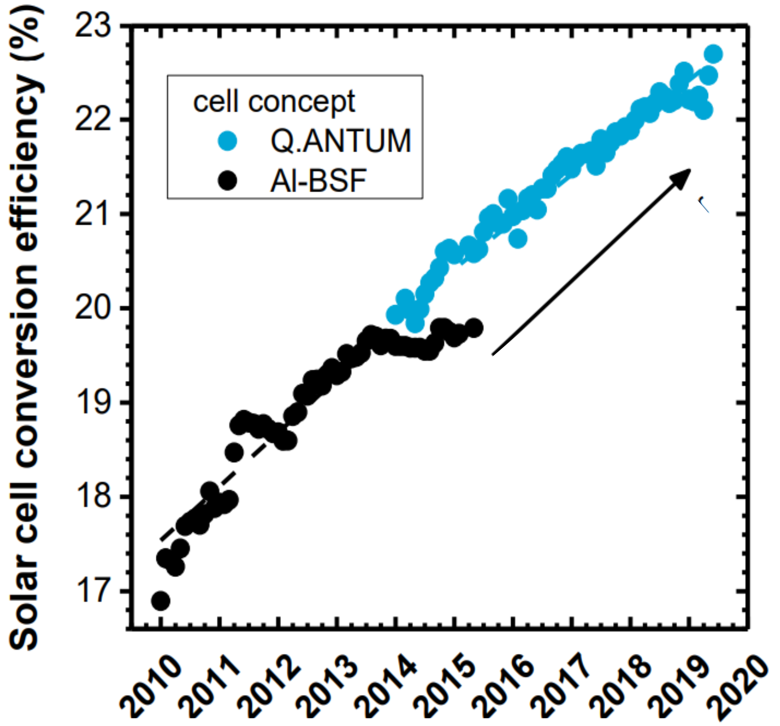
High recombination losses at Al/Si interface



Fabian et al, 7th Silicon PV 2017.

Passivated Emitter and Rear Cell (PERC)

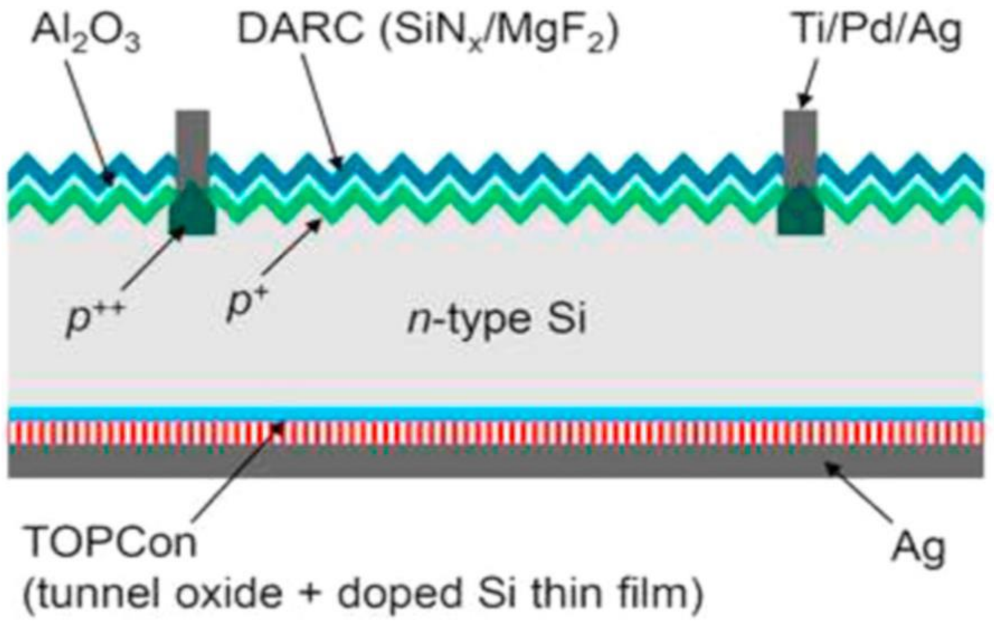


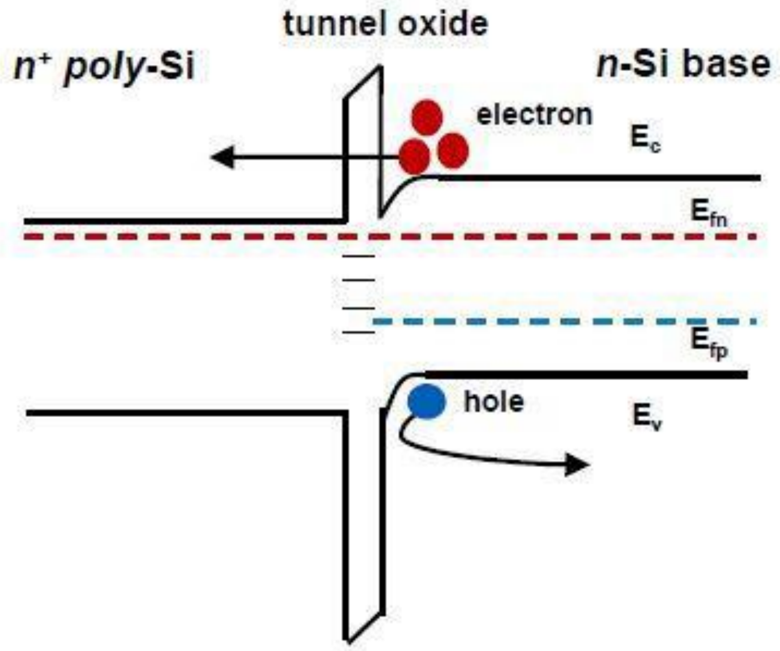


Stenzel et al, 36th EUPVSEC 2019.

Further improvements possible by using passivating contacts, switching to n-type silicon wafers and going to back-contact solar cells.

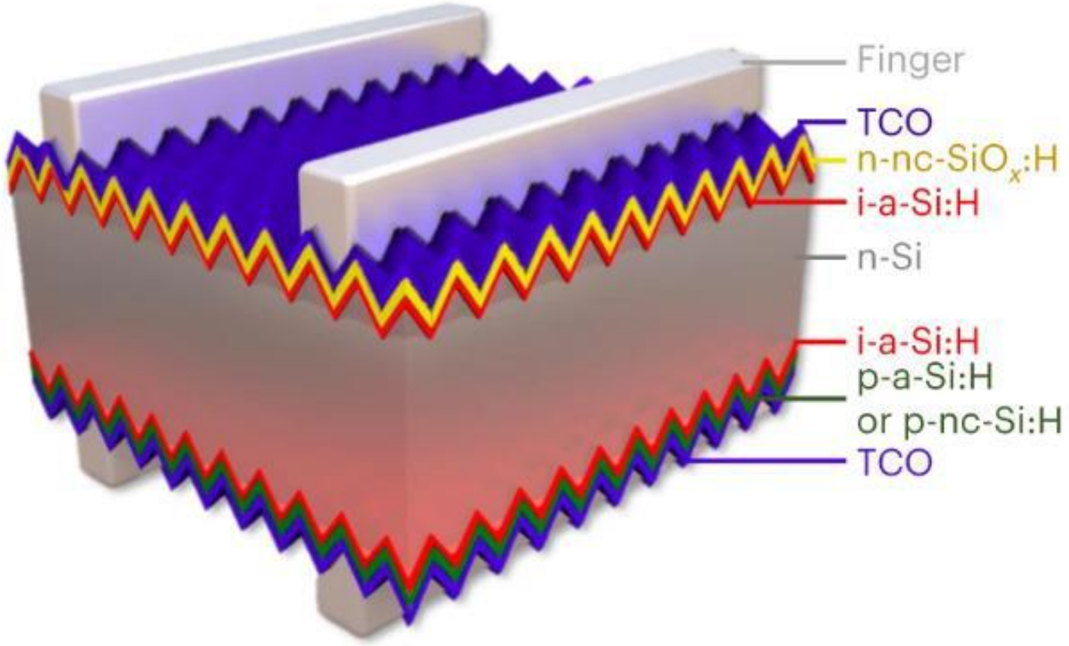
Tunnel Oxide Passivated Contact (TOPCon) Solar Cells





Efficiency: 27.08 % n-type TOPCon cell by Trina Solar

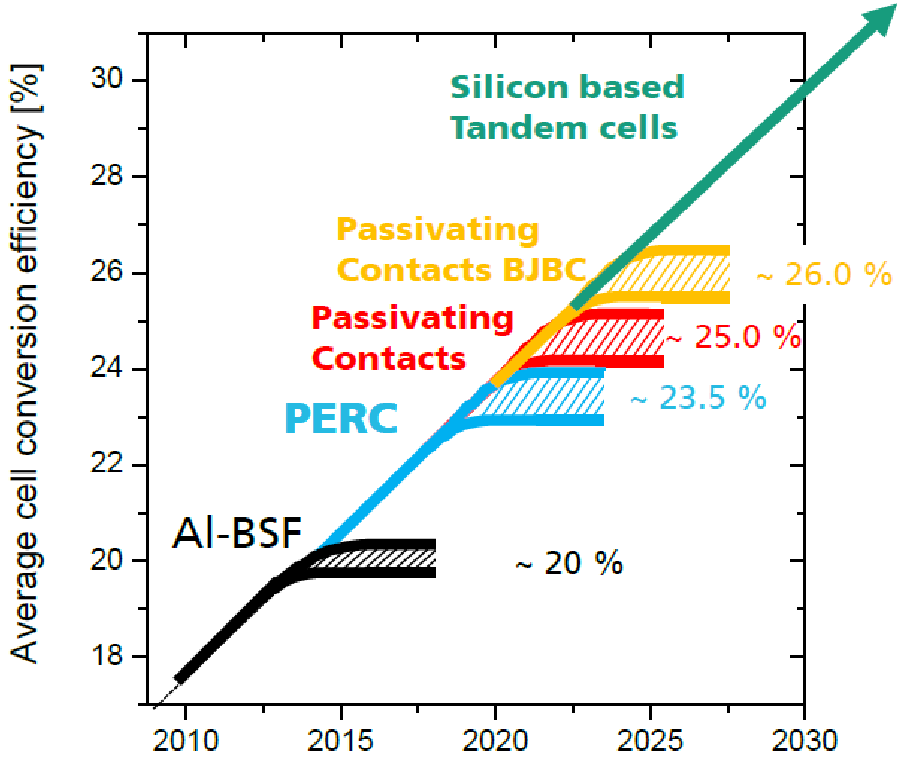
Heterojunction Cells



- n-type crystalline silicon absorber
- Amorphous silicon doped layers limit recombination at the electrode interface
- Intrinsically highly efficient carrier selective contacts
- Originally developed by Panasonic (Sanyo)
- High cost

Efficiency: 26.8% by Longi on full size wafer

Conclusions and Future Perspectives



- Proper manipulation of the **active phase**
- Key role of the physical and chemical **processes at the interfaces**
- Manufacturing and deposition **technology**
- Combination of different devices: **tandem** configuration.

Thank you for the attention!