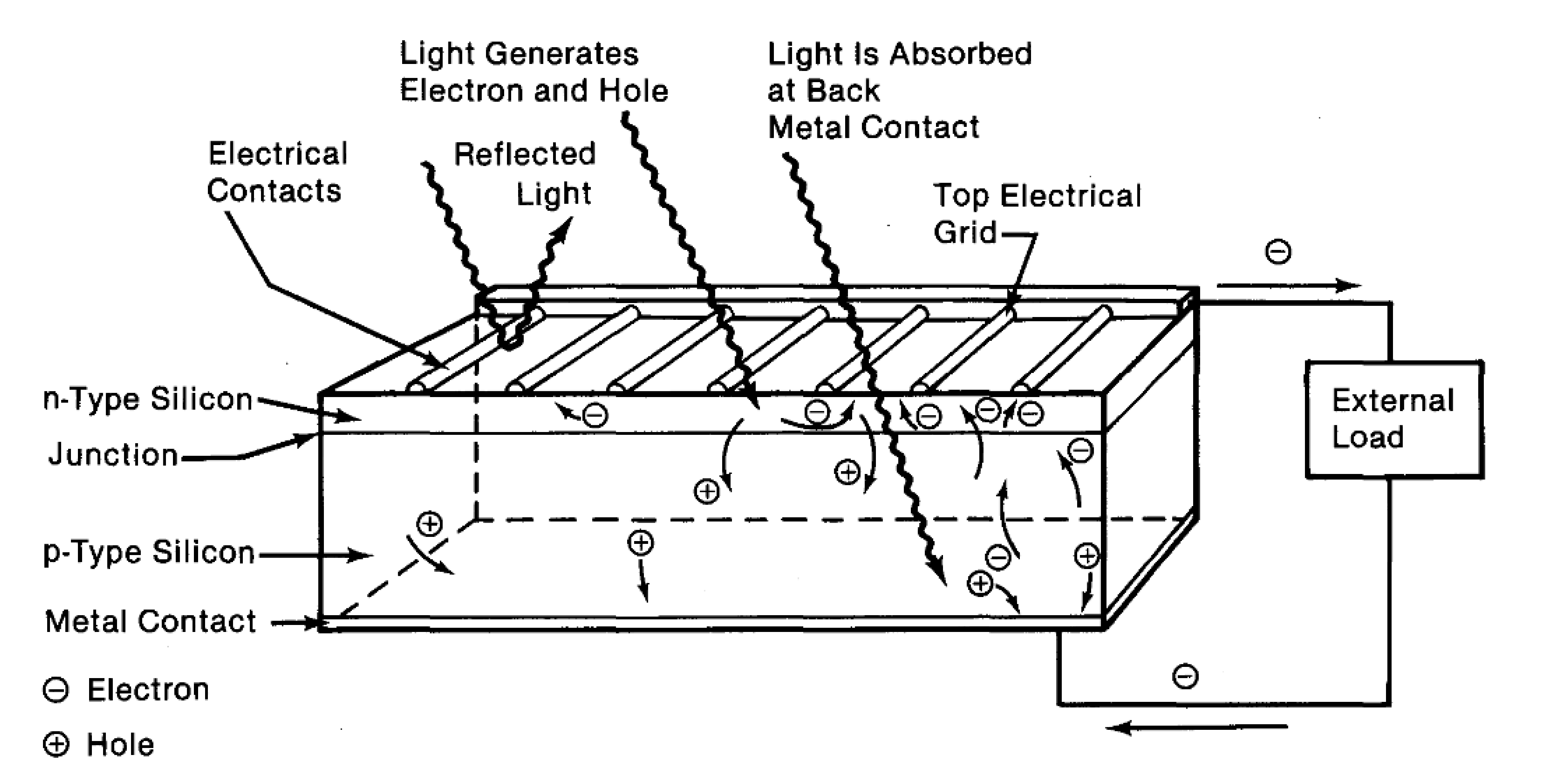
Structure of modern solar cells and their efficiency

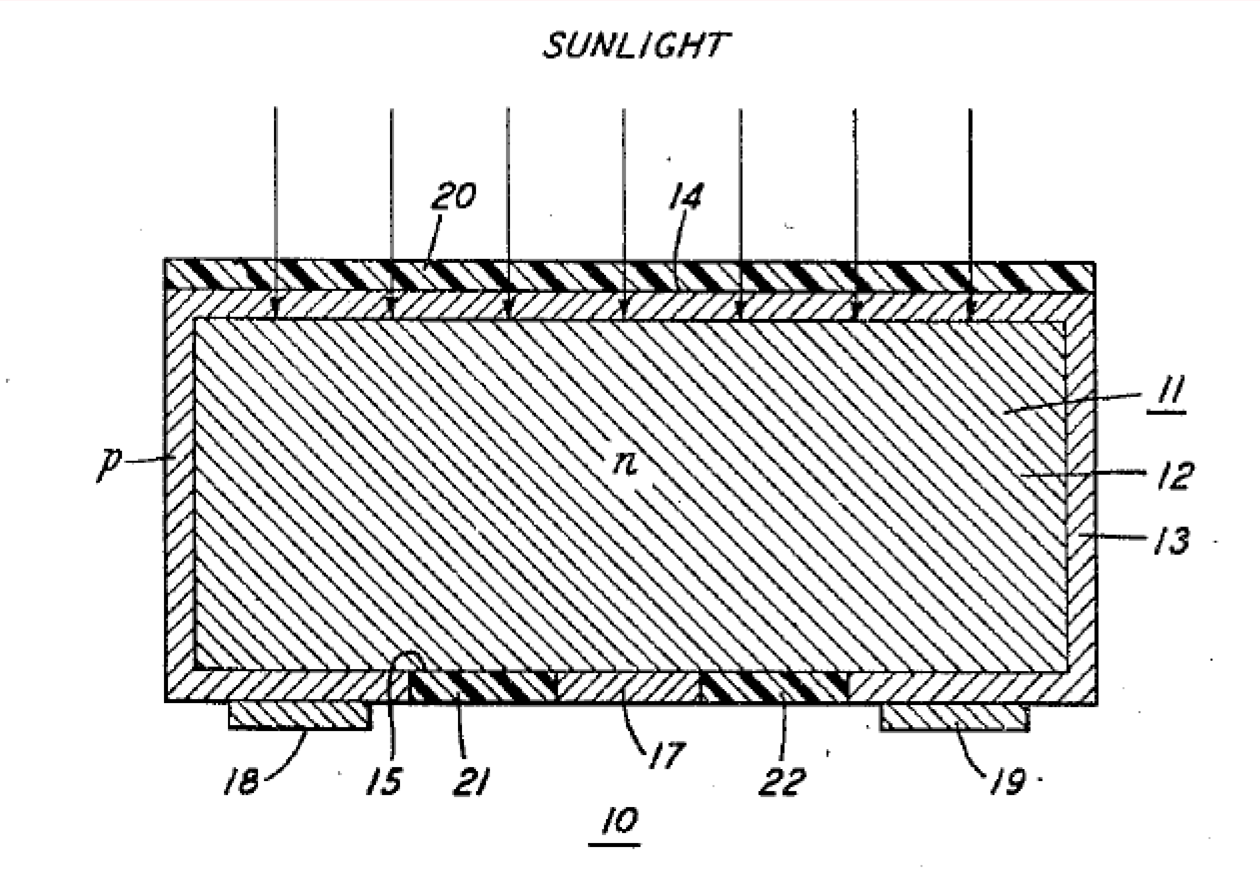
Basics of PV cells



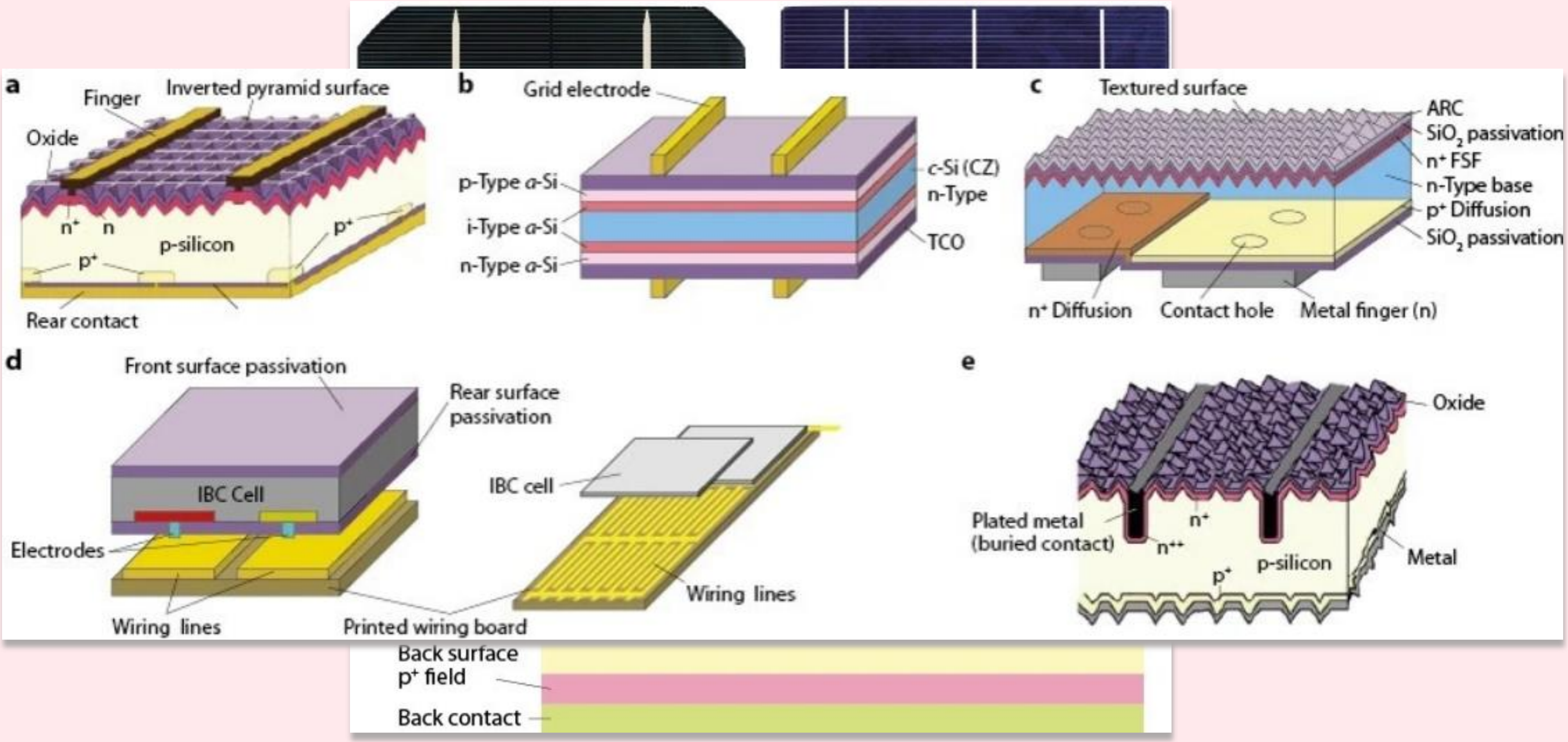
First solar cells

- First solar cell was created in 1883 by Charles Fritts
- Used selenium with a thin layer of gold coating
- Conversion rate of 1-2%

- First „useable” solar cells were made in the 50s from semiconductors
- Bell laboratories used silicon and achived a conversion rate of 6%



Structure of solar cells

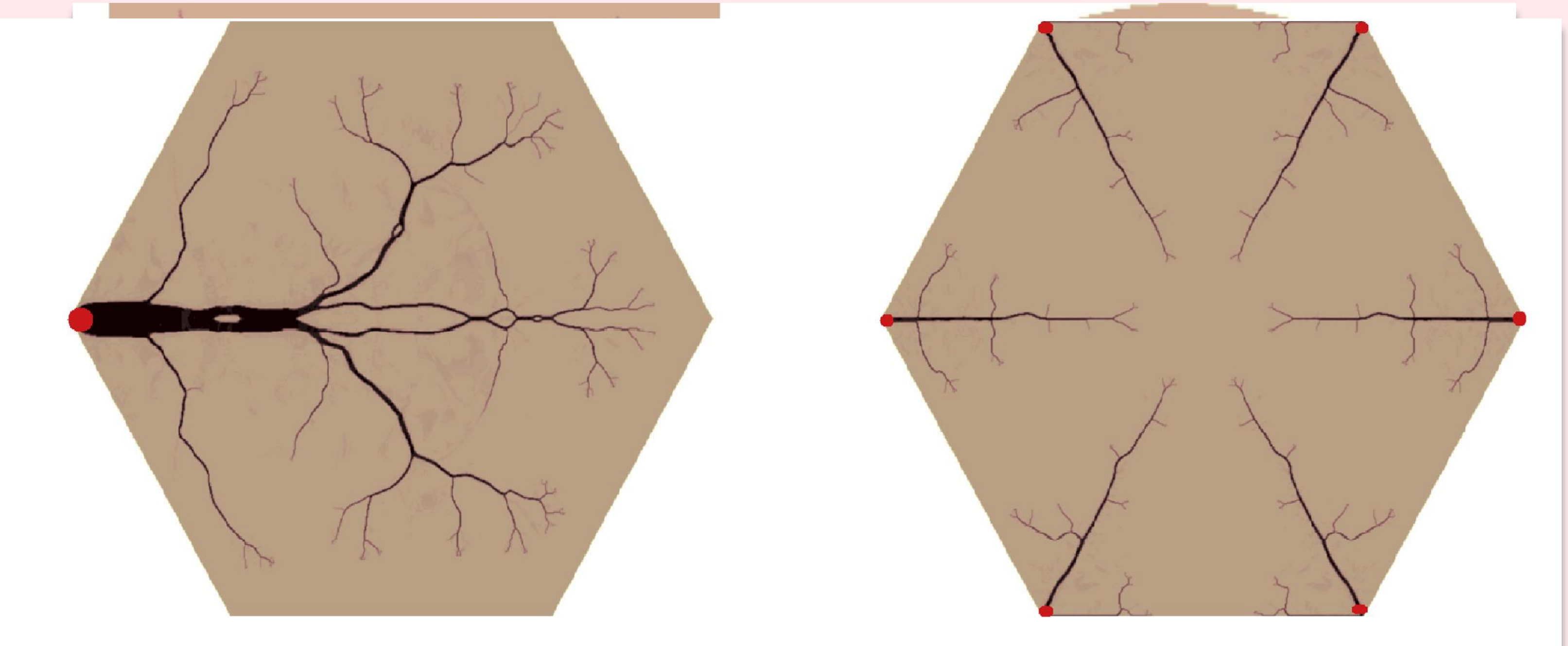


Limitations of efficiency

- Topological limitations
- Structural limitations
- Thermodynamic limitations
- Quantum efficiency

Topological limitation

- Not 100% of surface is used, electrodes shade a part of it
- Topological optimisation can help!



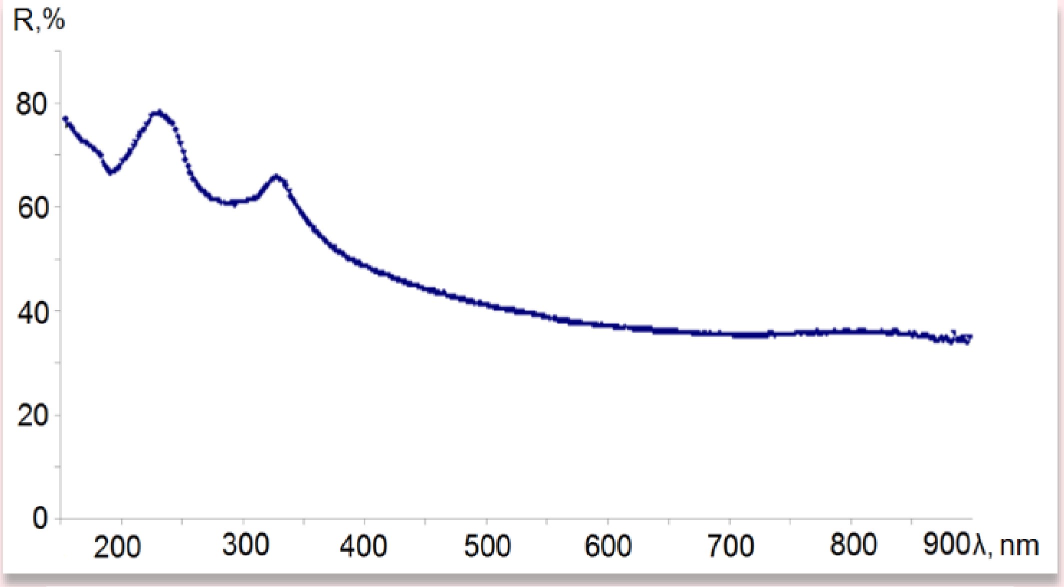
(a) Single-busbar model ($\eta = 13.55\%$) (b) Multi-busbar model ($\eta = 14.18\%$)

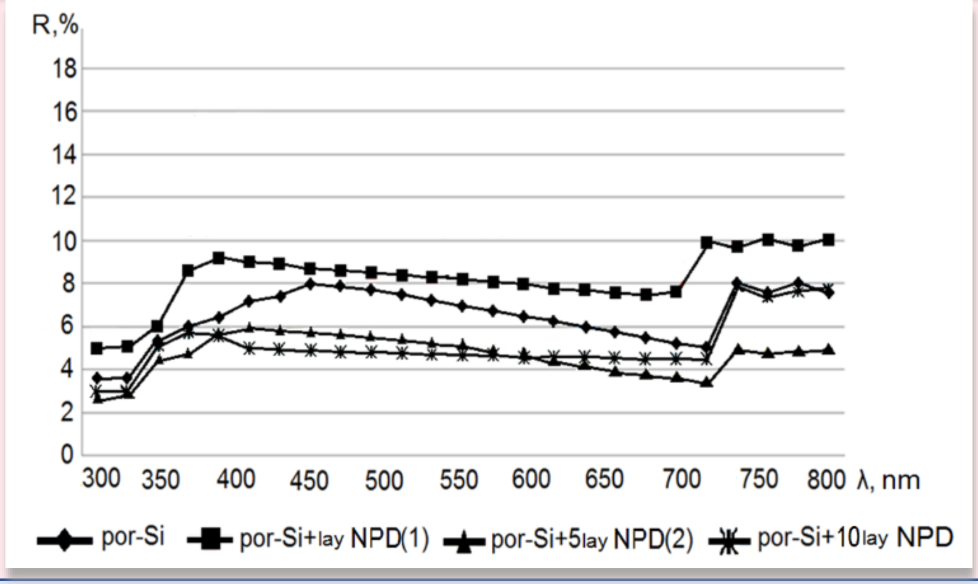
(a) Shape optimization (b) Topology optimization

Structural limitations

- Most solar cells are made out of silicium
- High refractive index leads to high reflectiveness
  - More than 35% of light can just simply reflect away

- Antireflecting coatings are used to counter this
- Materials such as SiO_2, TiO_2, SiN_x and BN_x is used
- Porous silicon (por-S) is also a good canditate
  - Nanodiamonds (DN) are a good choice for protection

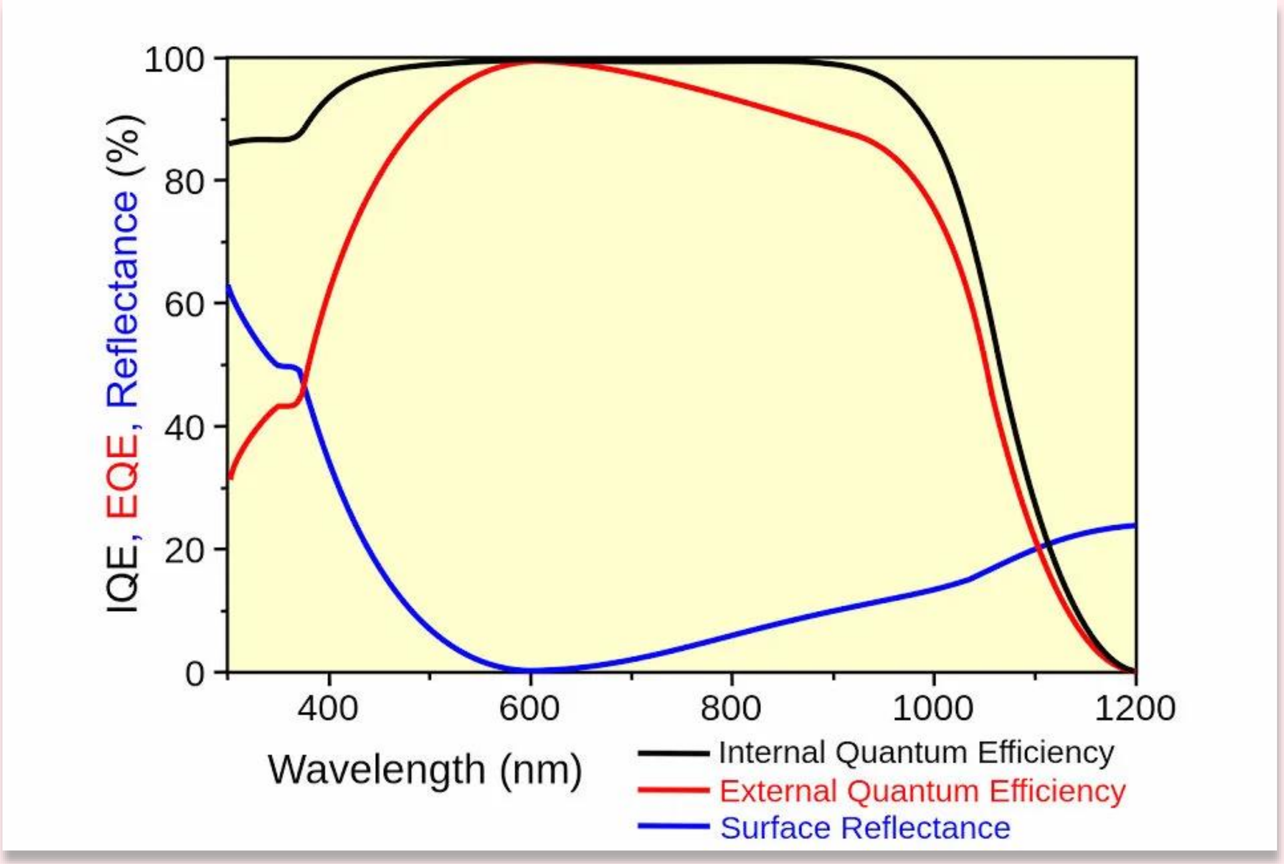




Quantum efficiency

- Percentage of photons that are converted to electric current
- There is a loss because of recombination
- Cannot be really countered

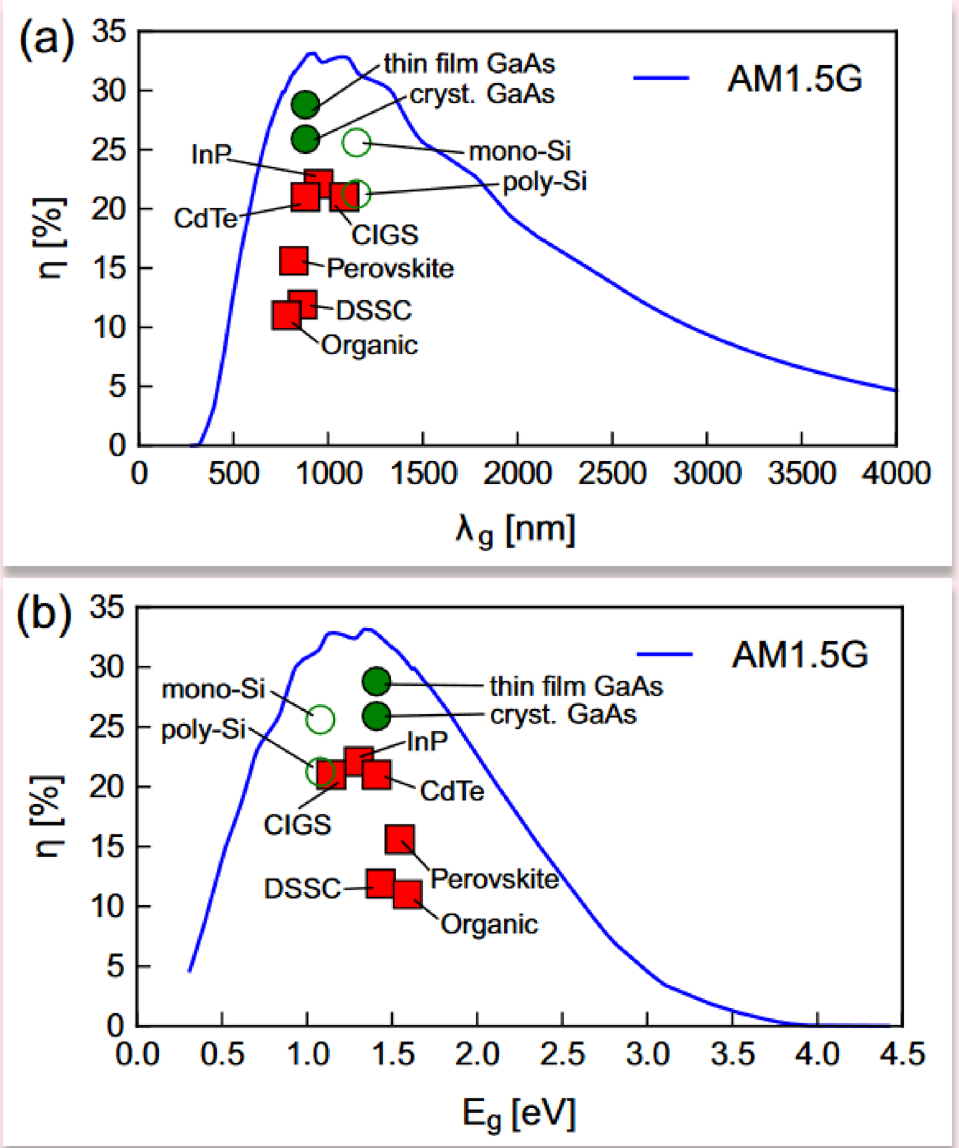
- There is also a possibility for more than 100% efficiency
- Multiple exciton generation or carrier multiplication

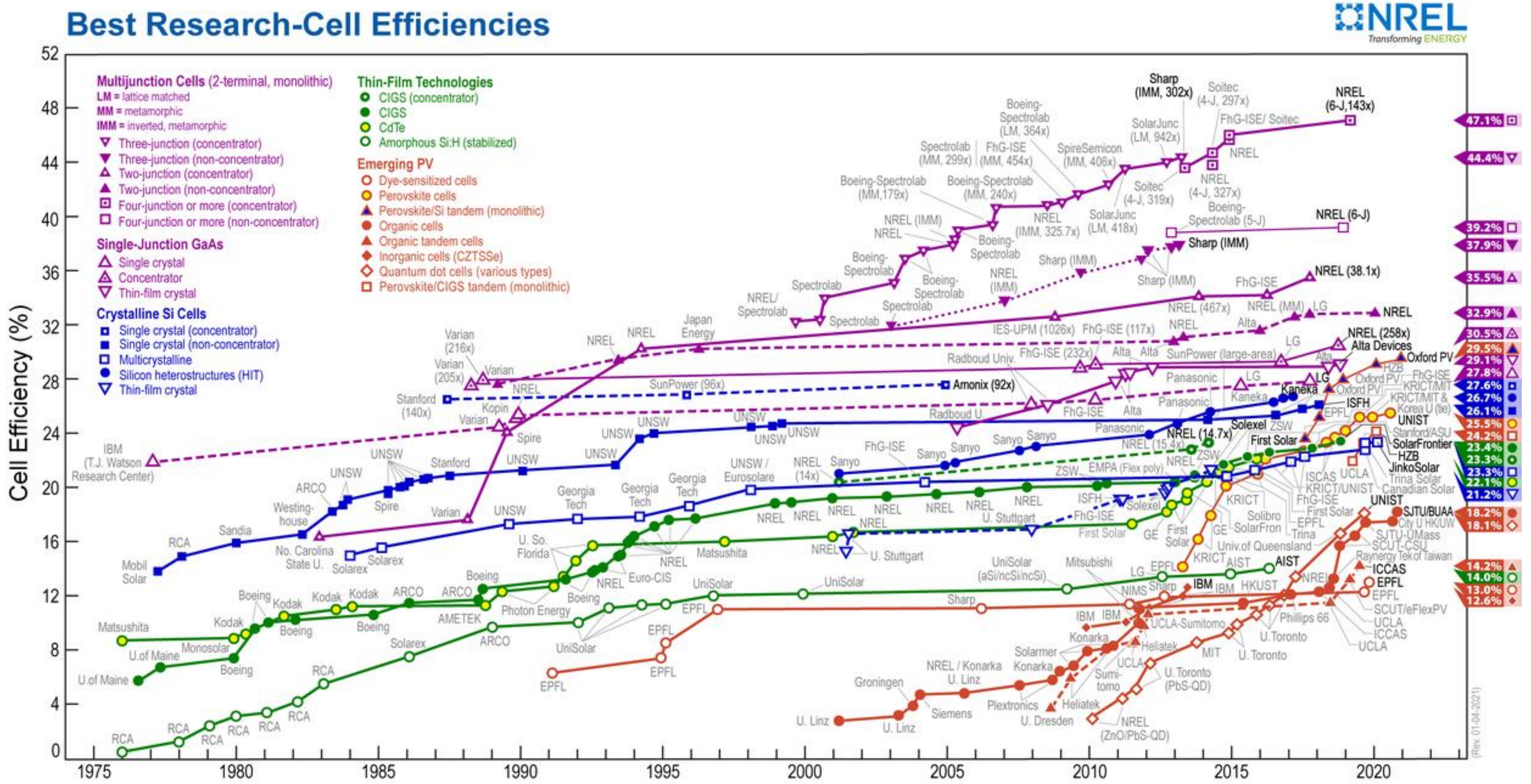


Thermodynamic limitations

- Theoretical limit with infinite junctions is 68.7%
- Shockley–Queisser limit (1961)
  - Assumes 100% quantum efficiency at 300 K
  - Assumed that only radiative recombination is possible
  - Aproximates light source as a 6000 K black-body
  - Gives the limit as 44% for a 1.1 eV band gap semiconductor

- Modern calculations give a maximal efficiency of around 33.16% at 1.34 eV band gap




Best Research-Cell Efficiencies
NREL
Transforming ENERGY
Cell Efficiency (%)
Multijunction Cells (2-terminal, monolithic)
LM = lattice matched
MM = metamorphic
IMM = inverted, metamorphic
Three-junction (concentrator)
Three-junction (non-concentrator)
Two-junction (concentrator)
Two-junction (non-concentrator)
Four-junction or more (concentrator)
Four-junction or more (non-concentrator)
Single-Junction GaAs
Single crystal
Concentrator
Thin-film crystal
Crystalline Si Cells
Single crystal (concentrator)
Single crystal (non-concentrator)
Multicrystalline
Silicon heterostructures (HIT)
Thin-film crystal
Thin-Film Technologies
CIGS (concentrator)
CIGS
CdTe
Amorphous Si:H (stabilized)
Emerging PV
Dye-sensitized cells
Perovskite cells
Perovskite/Si tandem (monolithic)
Organic cells
Organic tandem cells
Inorganic cells (CZTSSe)
Quantum dot cells (various types)
Perovskite/CIGS tandem (monolithic)
47.1%
44.4%
39.2%
37.9%
35.5%
32.9%
30.5%
29.5%
29.1%
27.8%
27.6%
26.7%
26.1%
25.5%
24.2%
23.4%
23.3%
23.3%
22.1%
21.2%
18.2%
18.1%
14.2%
14.0%
13.0%
12.6%
(Rev. 01-04-2021)

Thank you for your attention!

References

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