The Development of PV

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Introduction

- Solar Energy in the 1800's
  - In 1839, French scientist Edmond Becquerel discovered the photovoltaic effect.
  - The first solar panel was invented by Charles Fritts in 1883 where he coated a thin layer of selenium with an extremely thin layer of gold.
  - The resulting cells had a conversion electrical efficiency of only about 1%.

Source: https://ae-solar.com/history-of-solar-module/

Introduction

- Solar Energy in the 1900's
  - Einstein wrote a paper about the power of solar for which he eventually received the Nobel prize in 1921.
  - With the rise of semiconductors, Russel S Ohl described a process of forming silicon ingots that led to the first P-N junction cell in 1941.
  - Ohl cut a section from the ingot including the top, barrier, and bottom portions, and attached electrodes to the top and bottom portions, yielding the first silicon solar cell.
  - The solar era began in 1950 when Bell Laboratory scientists focused on photovoltaic (PV) developments and began utilizing silicon to produce solar cells.
  - This breakthrough is credited to Daryl Chapin, Calvin Fuller, and Gerald Pearson which produced an efficiency of 4% PV.
  - In the 1960s and 1970's, the production of solar panels was made possible. However, it was too expensive.

Source: https://ae-solar.com/history-of-solar-module/

Introduction

- Solar Energy in the 2000’s
  - In the 1950s, the world had less than a watt of solar cells powering electrical equipment.
  - Fast-forward to the 21st century, solar panels provide electricity to millions of houses worldwide, power up buildings, satellites and provide clean energy all around the world.
  - According to the IEA report, the global installed solar capacity reaches 510GW in 2023, and the global installed renewable energy capacity is expected to reach 7,300GW between 2023 and 2028.

Source: https://ae-solar.com/history-of-solar-module/

Introduction

- The price of silicon PV cells in the 1950s was US$76/Watt which significantly declined to US$0.10/Watt in 2023. The average cost of a solar panel dropped by 90% from 2010 to 2020.
- Major types of Solar panels available today in the market are monocrystalline, polycrystalline, and thin-film panels.

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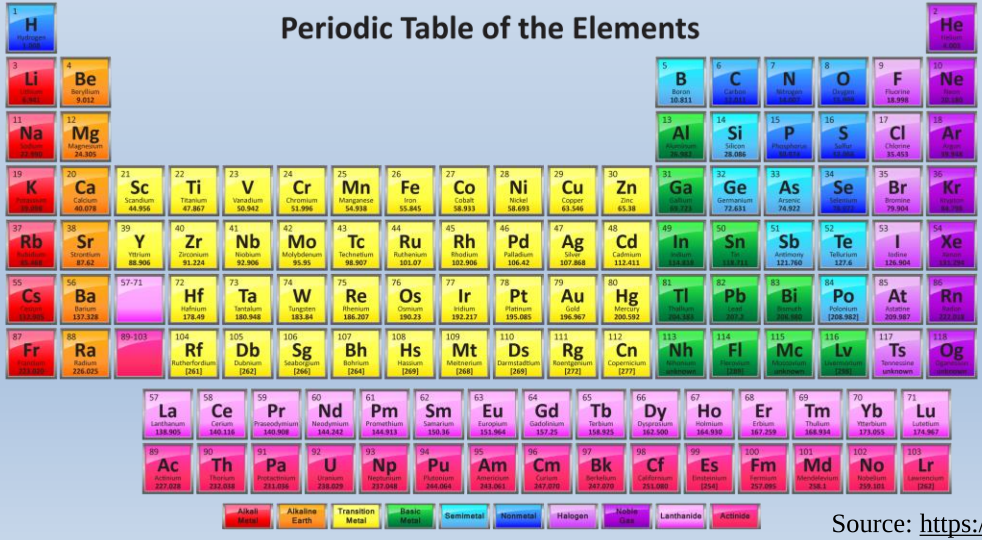
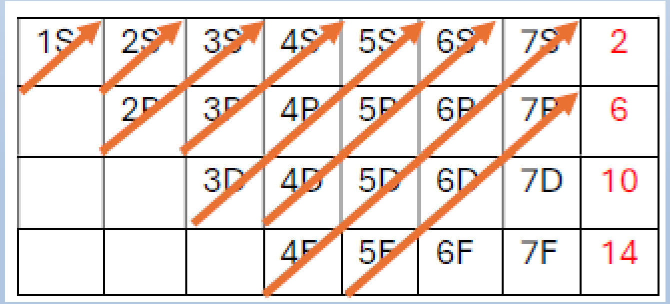
Theory of the PV

- A photovoltaic cell is a semiconductor diode. To understand what they do differently from other substances, we have to look at the periodic table of elements.

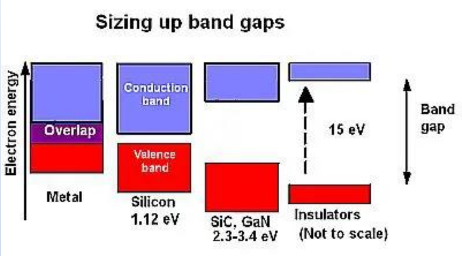


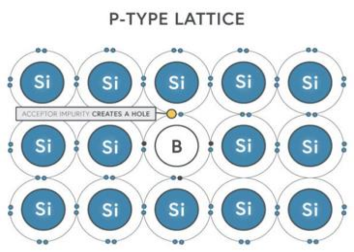


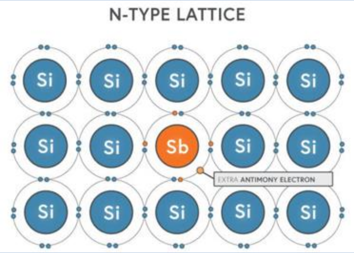
Source: https://g2voptics.com/photovoltaics-solar-cells/theory-of-solar-cells/

Theory of the PV

- Band gap and Semiconductor: Band gap is defined as the energy difference between the top valence band and the bottom of the conduction band
- Covalent Bond: A covalent bond is a chemical bond that involves the sharing of electron pairs between atoms.
- P-Type and N-Type Semiconductor
  - P-Type: Mix a small amount of boron or gallium in silicon
  - N-type: Mix a small amount of phosphorus, arsenic, or antimony in silicon



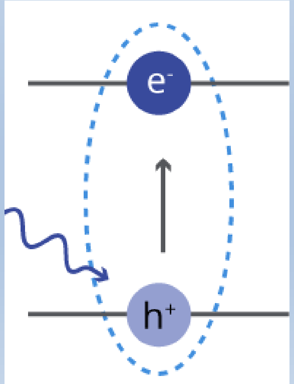




Source: https://www.testandmeasurementtips.com/how-big-is-the-band-gap-a-heated-discussion-faq/
Source: https://g2voptics.com/photovoltaics-solar-cells/theory-of-solar-cells/

Photovoltaic Effect

- The photovoltaic effect is the phenomenon where certain materials generate electric current when exposed to light.
- When photons strike a photovoltaic cell, they can transfer enough energy to free electrons in the semiconductor material, allowing them to flow as an electric current.

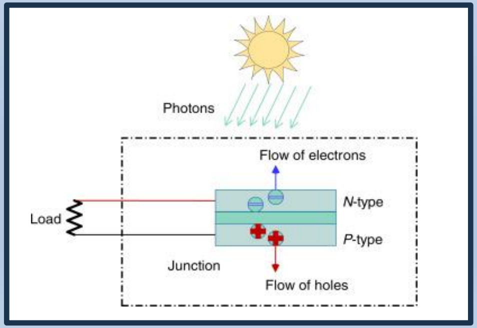


$E = hf$

h: Plank Constant

h: 6.626×10^{-34} J/Hz

h: 4.13567×10^{-15} eV/Hz



Source: https://www.sciencedirect.com/topics/engineering/photovoltaic-effect

Efficiency of Crystalline Si Cells

- The theoretical maximum efficiency of a solar cell is determined by the Shockley-Queisser limit.
- For a single-junction solar cell made of a single material, the Shockley-Queisser limit is approximately 33.7% under standard test conditions.
- Several factors limit the actual efficiency of a solar cell
    - Bandgap mismatch
    - Non-ideal absorption.
    - Charge carrier recombination.
    - Resistive losses.
    - Temperature effects.
    - Reflection and shading.
    - Angle of incidence:
- In practice, most commercial silicon-based solar cells have efficiencies between 15% and 23%.

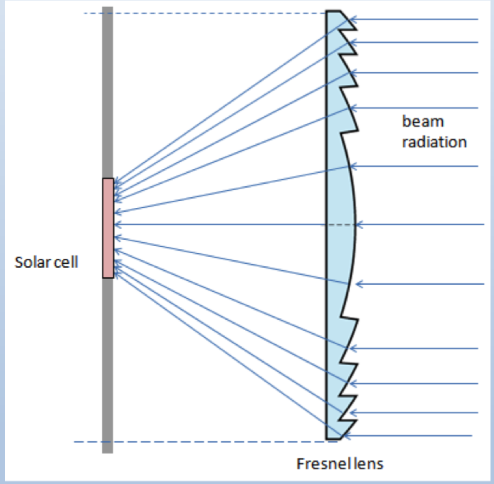
Evolution of Solar Cell Design

- The first main goal of solar cell design is to increase absorption, to get more energy out of each cell.
  - After the first solar cell was created in 1954, one of the next big advances in design happened in the 1980s, with the development of so-called black cells.
  - These solar cells increased absorption by lowering the amount of reflected light.

Source: https://g2voptics.com/photovoltaics-solar-cells/theory-of-solar-cells/

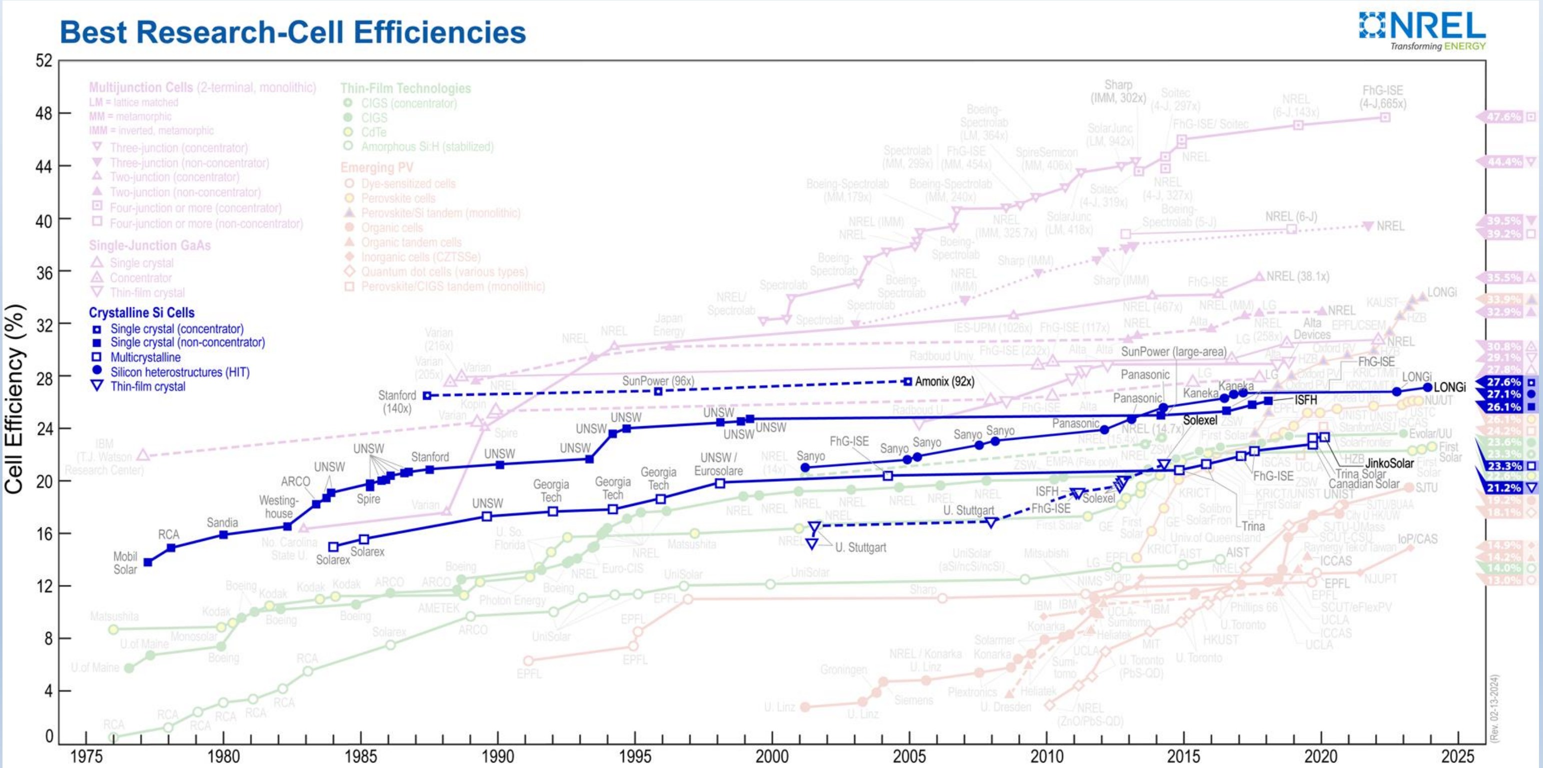
Evolution of Solar Cell Design

- Unlike conventional PV, Concentrator photovoltaics (CPV) uses lenses or curved mirrors to focus sunlight onto small and highly efficient solar cells.
- CPV systems often use solar trackers and sometimes a cooling system (CHP) to further increase their efficiency.



Source: https://www.e-education.psu.edu/eme812/node/537

Efficiency of Crystalline Si Cells



Source: NREL

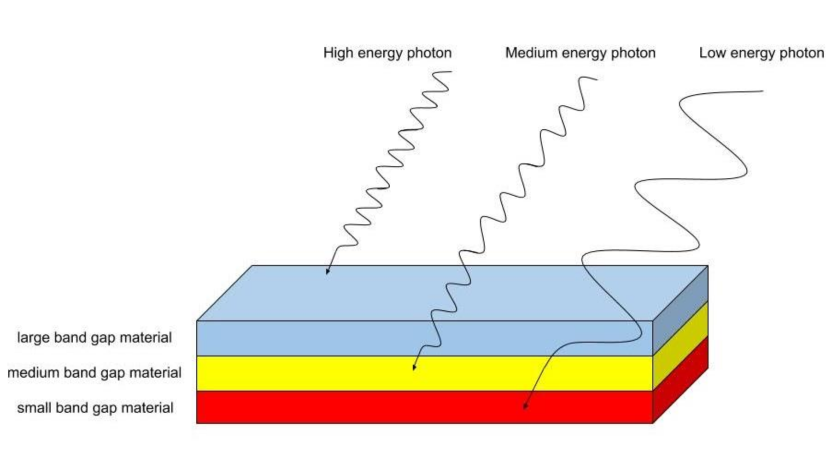
Multijunction PV

- The multijunction PV stacks PVs with different band gaps to capture more of the solar spectrum.
- By using III-V materials such as gallium arsenide (GaAs), aluminum indium phosphide (AlInP), aluminum gallium indium phosphide (AlGaInP), gallium indium phosphide (GaInP), and indium phosphide (InP), etc.) Multijunction PV demonstratea high efficiency.

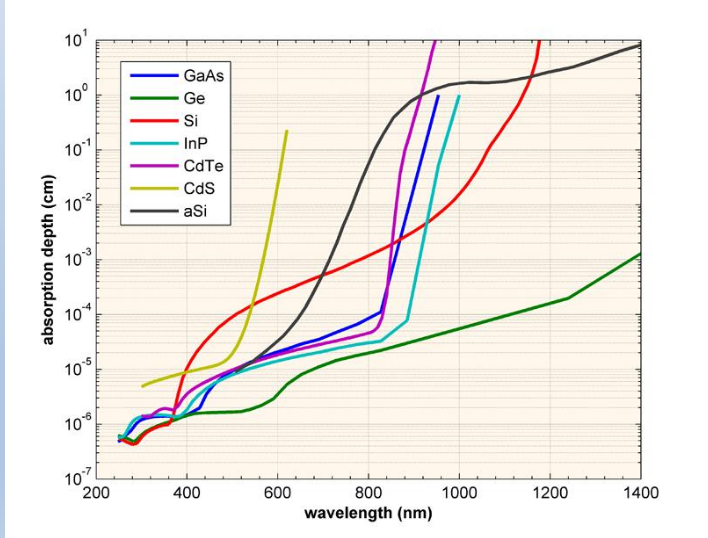
Source: https://www.energy.gov/eere/solar/multijunction-iii-v-photovoltaics-research

Multijunction PV

- The absorption depth is the distance into the material at which the light drops to about 36% of its original intensity.

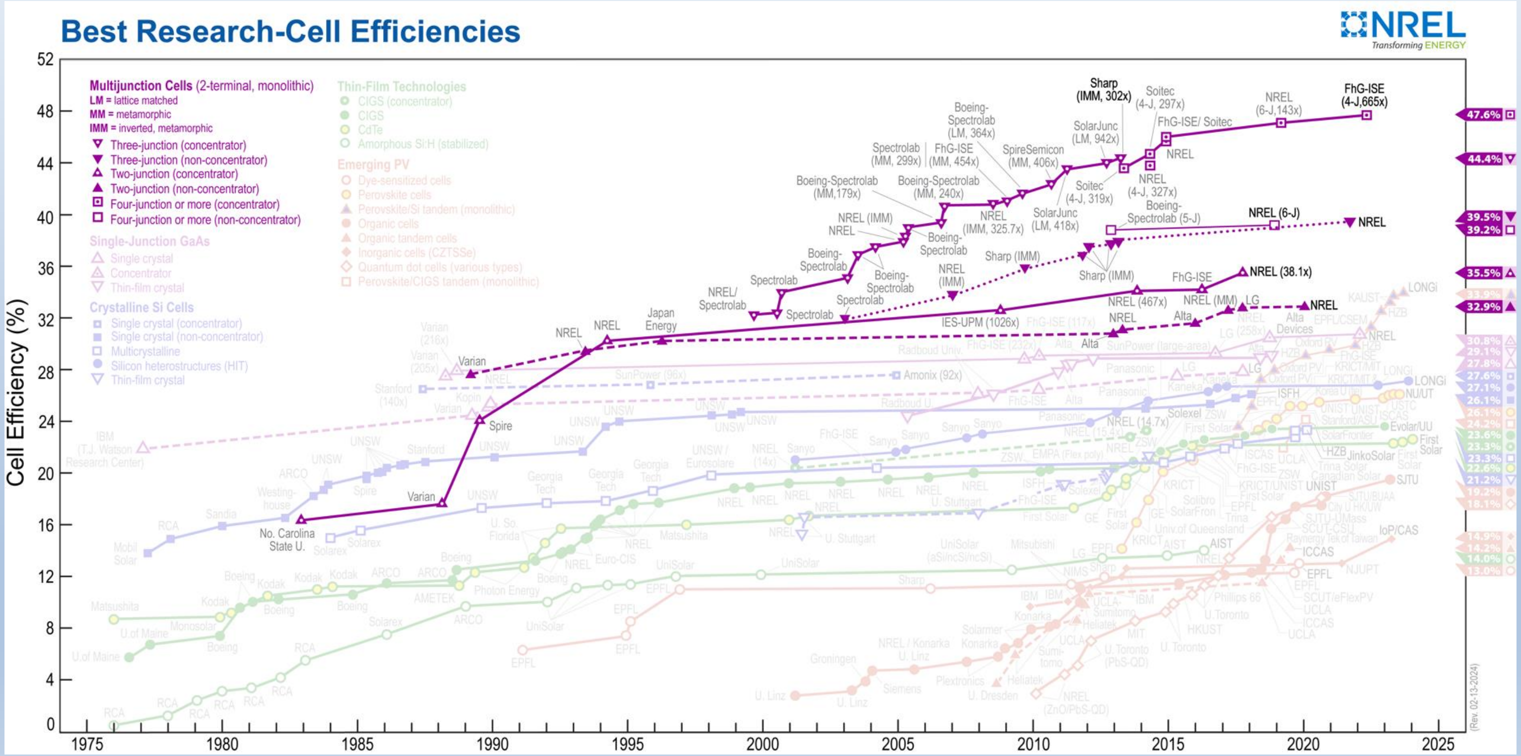


https://eng.libretexts.org/Bookshelves/Materials_Science/Supplemental_Modules_(Materials_Science)/Materials_and_Devices/Multi-junction_Photovoltaics



Source: https://www.pveducation.org/pvcdrom/pn-junctions/absorption-depth

Efficiency of Multijunction PV



Source: NREL

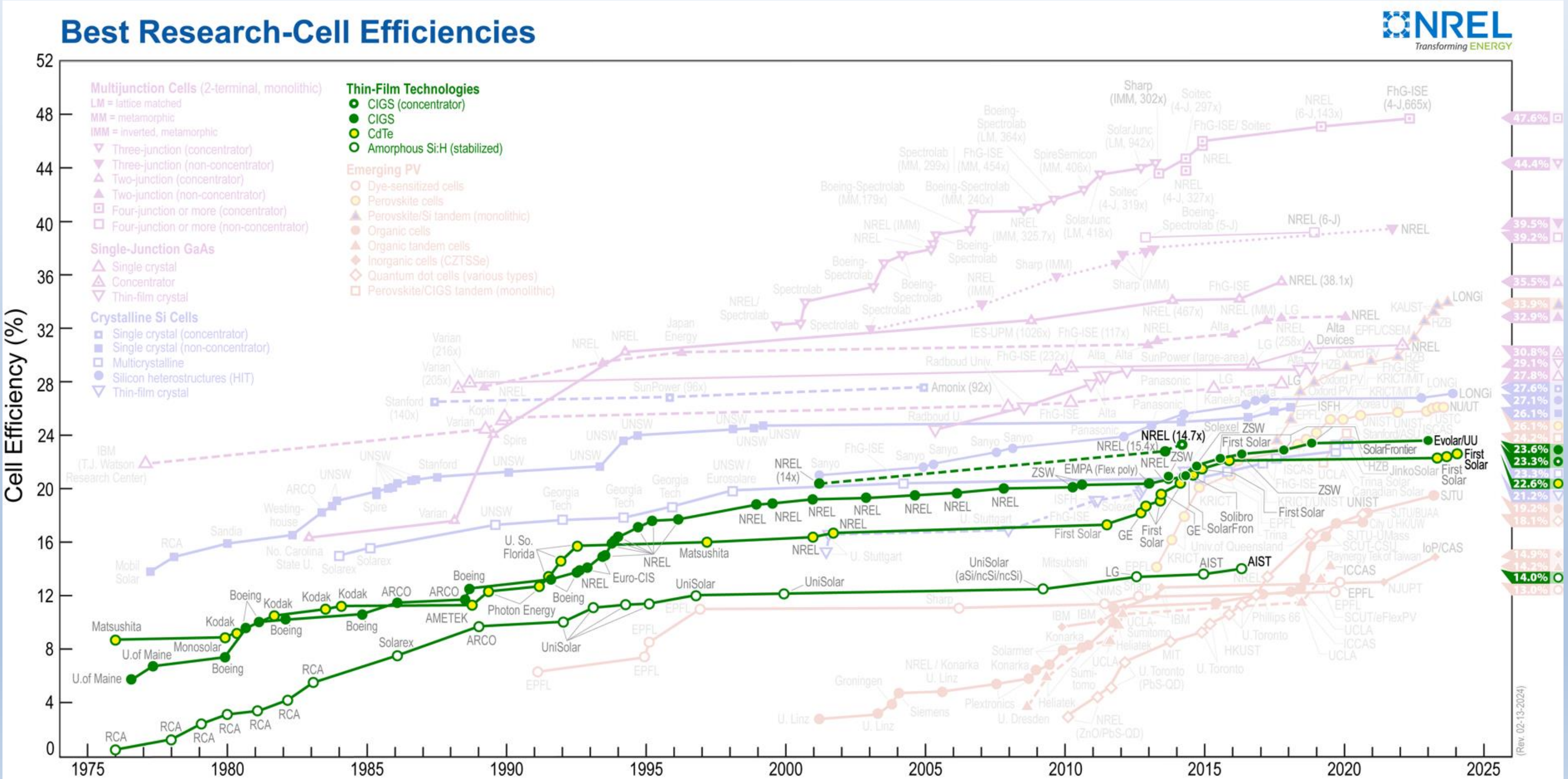
Thin Film PV

- Thin-film solar panels convert sunlight into electricity using a thin layer of photovoltaic (PV) material
- The Theoretical efficiency limit of thin-film photovoltaic (PV) cells is constrained by the Shockley-Queisser limit.

Efficiency of Thin Film PV

- The theoretical efficiency limits for some common thin-film PV materials are approximately as follows:
  - Amorphous Silicon (a-Si): 10-12%.
  - Cadmium Telluride (CdTe): 29-30%.
  - Copper Indium Gallium Selenide (CIGS): 20-23%.
- The actual efficiencies of commercial thin-film PV cells may be lower due to factors such as material quality, device design, and manufacturing processes.

Efficiency of Thin-Film PV



Source: NREL

Organic Photovoltaics (OPV)

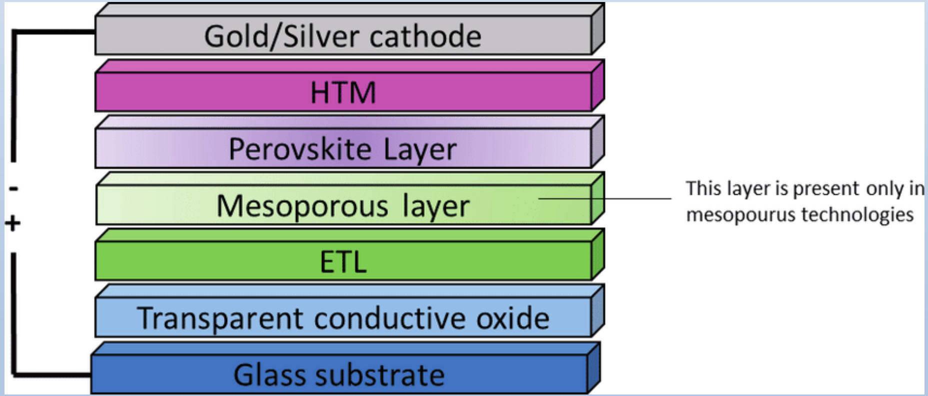
- Organic photovoltaics (OPV) are a type of thin-film photovoltaic technology that uses organic molecules or polymers to convert sunlight into electricity.
- Unlike traditional silicon-based solar cells, which rely on inorganic semiconductors, OPV cells utilize organic materials, often carbon-based compounds.
- OPV has lower efficiencies (5 -10%) than silicon-based solar cells and shorter lifespans due to the degradation of organic materials over time.

Perovskite Solar Cells

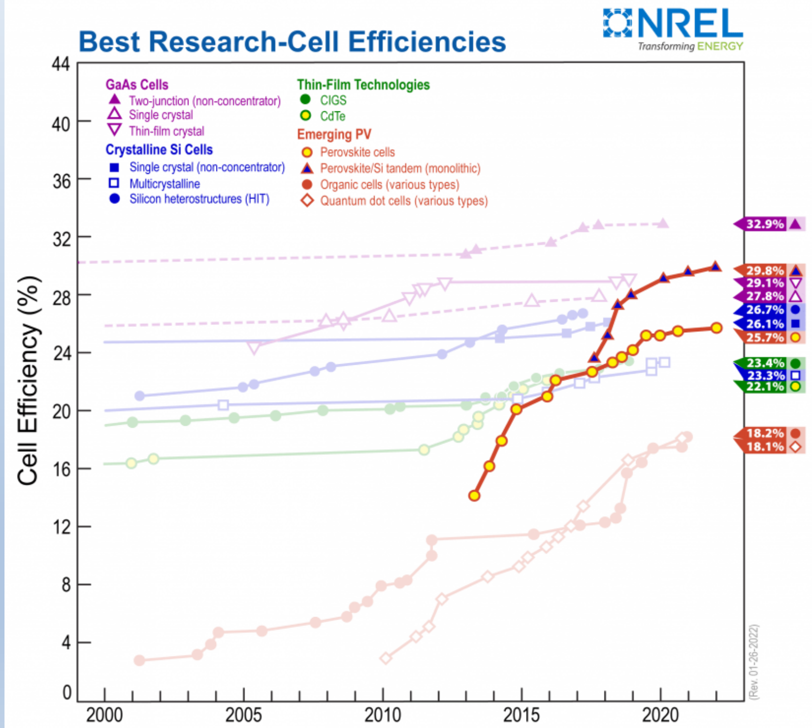
- Perovskite solar cells are a type of thin-film cell and are named after their characteristic crystal structure.
- Perovskite materials have a specific crystal structure that enables them to efficiently convert sunlight into electricity.
- Perovskite solar cells have shown remarkable progress in recent years with rapid increases in efficiency, from reports of about 3% in 2009 to over 25% today.

Source: https://www.energy.gov/eere/solar/perovskite-solar-cells

Perovskite Solar Cells



Source: https://www.researchgate.net/figure/General-structure-of-a-perovskite-solar-cell_fig2_338480865



Source: https://www.energy.gov/eere/solar/perovskite-solar-cells

Perovskite Solar Cells

- Advantages and Disadvantages of the Perovskite PV
  - The power conversion efficiency of perovskite solar cells is high and inexpensive compared to existing photovoltaic cell technologies.
  - Perovskite tops the list when comparing open-circuit voltage versus bandgap. The photon energy lost during the conversion of light to electricity is less in perovskite solar cells compared to other cells.
  - The service life of perovskite solar cells is less than silicon solar cells, and they suffer from instability and degradation issues.

Source: https://resources.system-analysis.cadence.com/blog/msa2021-an-overview-of-the-types-of-perovskite-solar-cellsells

Tandem Solar Cells

- While all solar cells with more than one bandgap are multijunction solar cells, a solar cell with exactly two bandgaps is called a tandem solar cell.
- Tandem cells are stacks of *p*-*n* junctions, each of which is formed from a semiconductor of different bandgap energy.
- Each responds to a different section of the solar spectrum, yielding higher overall efficiency

Source: https://www.energy.gov/eere/solar/solar-photovoltaic-cell-basics

Quantum Dot Solar Cells

- Quantum dot solar cells conduct electricity through tiny particles of different semiconductor materials just a few nanometers wide, called quantum dots.
- Quantum dots provide a new way to process semiconductor materials.

Source: https://www.energy.gov/eere/solar/solar-photovoltaic-cell-basics

Quantum Dot Solar Cells

- Disadvantages and Advantages
  - Lower efficiency.
  - Easy to make into solar cells. They can be deposited onto a substrate using a spin-coat method, a spray, or roll-to-roll printers like the ones used to print newspapers.
  - Quantum dots come in various sizes and their bandgap is customizable.

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Others

- **Bifacial Solar Panels**
  - Bifacial solar panels can generate electricity from both the front and rear sides of the module, increasing energy yield compared to traditional monofacial panels.
  - Bifacial modules are particularly well-suited for installations with reflective surfaces, such as snow-covered ground or white rooftops, and offer greater design flexibility.

Source: https://www.solarpowerworldonline.com/2018/04/what-are-bifacial-solar-modules/

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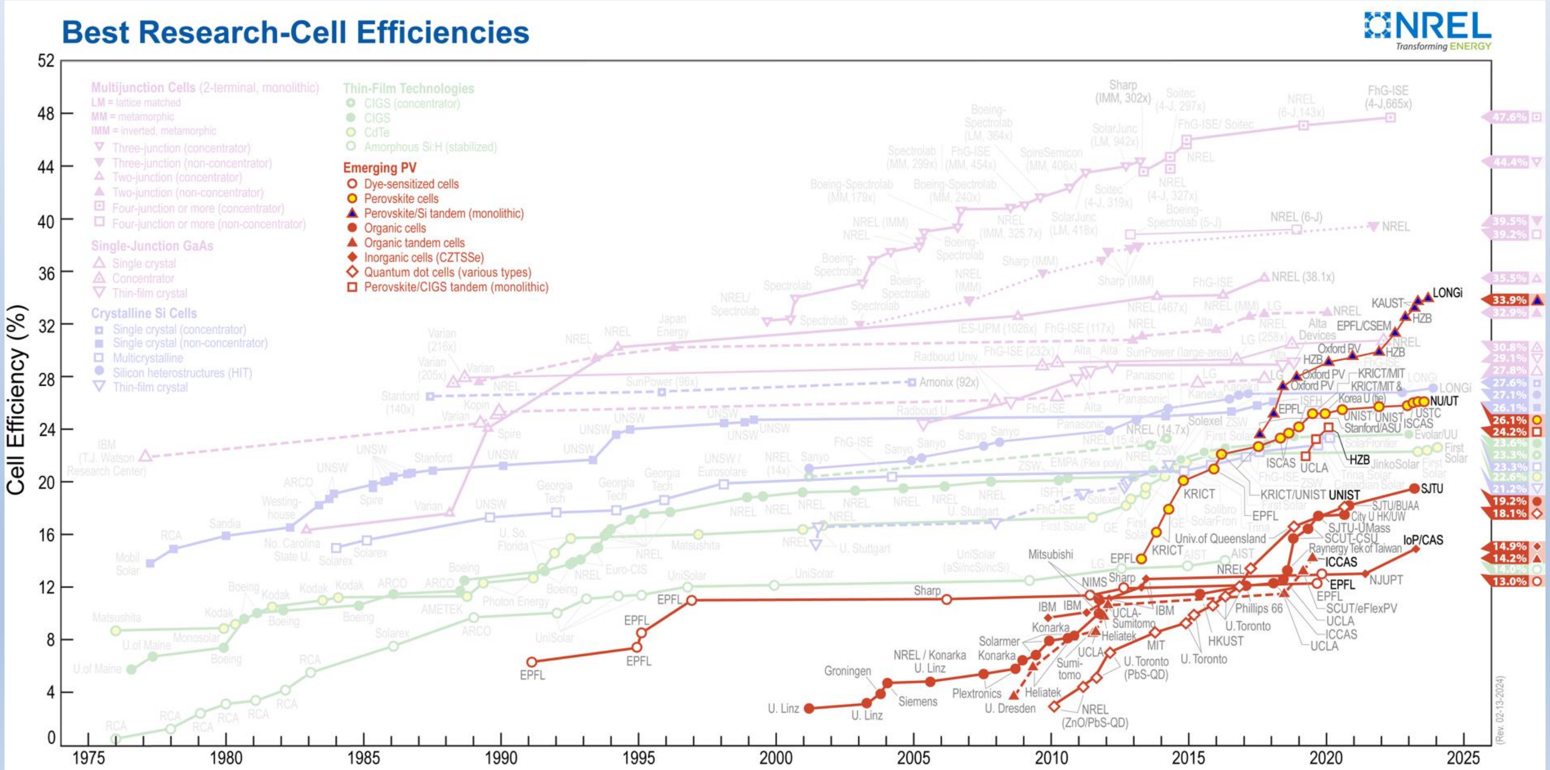
PV-Thermal

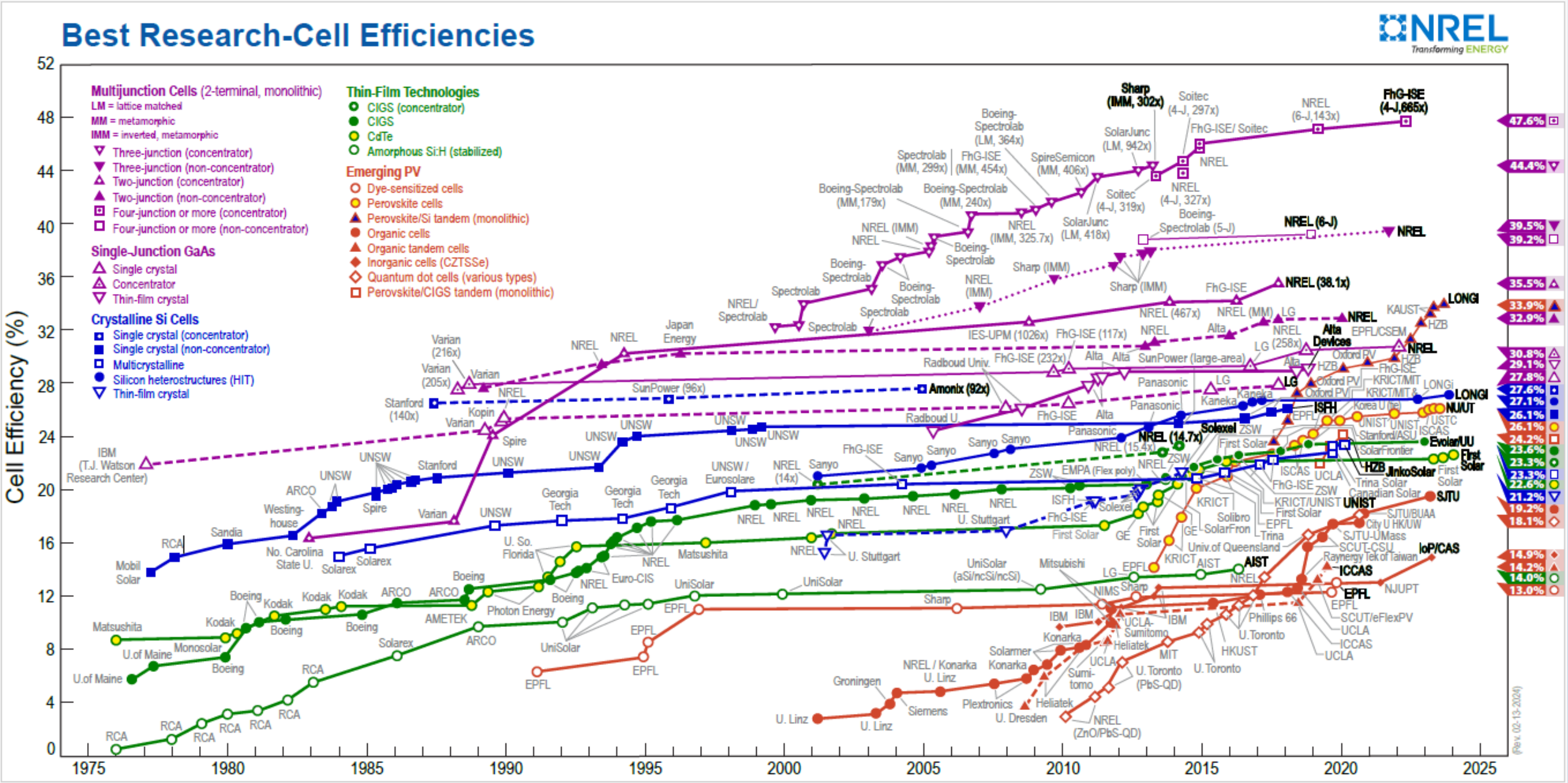
- PV-T technology is a hybrid system that combines PV panels with solar thermal collectors and capitalizes on the untapped heat energy of the PV system.
- Water or air flowing through the thermal collector removes and captures heat from the PV cells, allowing a larger portion of the solar energy incident on the collector to be turned into either thermal or electrical energy.

Efficiency of Emerging PV



Source: NREL

Best Research Cell Efficiency



Source: NREL

Thank You !!!