

A Review on Photovoltaic Technologies, Design and its Efficiency

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Abstract: *The primary source of all energies can be thought of as the sun's energy. It can be produced directly via a variety of methods, like maximizing the use of sunshine. Thermal energy can be produced utilising solar energy or electricity. Photovoltaic (PV) cell use is widespread in the solar energy industry. By presenting recent innovations in the area, the primary goal of this review research is to assist anyone navigating the solar energy industry. The development of a potential difference at the intersection of two unique semiconductor materials is how photovoltaic energy is converted. The materials used for solar cells should be non-toxic, cheap and abundant. In order to scale up the various technologies, it is crucial that the ingredients used are abundant. For an advanced crystalline silicon solar cell without light concentration, We began our discussion of the various PV technologies. Thin film Unlike the wafers that serve as the foundation for first-generation PV, solar cells are built of significantly thinner sheets. Due to the current price decline in wafer-based solar cells, most thin-film solar cells have not yet become economically viable. Over the past two decades, these thin film technologies have continuously become more efficient. The performance of CIGS and CdTe solar cells is very comparable, with a record efficiency of 22.6% for the CIGS solar cell from ZSW and 22.1% for the cadmium telluride. As we can see, research on organic Photovoltaics (PV) has only been going on for the past 15 years, with the exception of dye-sensitized solar cells. The Hong Kong UST has achieved a record efficiency of 11.5% for organic solar cells during that time and Sharp has reached a record efficiency of 11.9% for dye sensitized solar cells. Perovskite solar cells have not yet achieved a stable efficiency.*

Keywords: CIGS, Dye Sensitized Solar Cells, Non-Toxic, Perovskite, Photovoltaics, Thin Films

1. Introduction

The history of the silicon-based solar cell starts in the early 1940s, when the photo-electric behaviour of silicon was accidentally observed. But it wasn't until 1954 that three scientists at the Bell Laboratories in New Jersey managed to make the first silicon-based solar cell. Gerald Pearson, an electrical engineer, Daryl Chapin, a chemist, and Calvin S. Fuller, a physicist, are pictured from left to right. Early solar modules with big batteries for storage were created for uses like communications since the cell's conversion efficiency, which was around 6% at the time, was seen to be quite promising. The aerospace industry was primarily responsible for the development of Photovoltaics throughout the 1950s with the aim of supplying energy to satellites and other space applications. **The record efficiency of crystalline silicon has increased from around 14% in 1975 to a record of 26.6% now held by Kaneka [1].** This introduction to the different PV technologies and gain an in-depth understanding of the various module architectures, manufacturing and processing methods and advantages and limitations of each of these technologies.

2. Photovoltaic Generation

Depending on the primary material utilized, PV cell technologies are typically divided into five generations:

1. Crystalline silicon
2. Thin film Technologies
3. Perovskite Solar cells
4. Organic Photovoltaics
5. Hybrid Photovoltaics

2.1. First – Generation: Crystalline Silicon

For Photovoltaics to be used at a big scale—on the order of terawatts—there are some criteria. The first successful solar cell was made from crystalline silicon, which still is by far the most widely used PV material. Crystalline silicon solar cells use boron and phosphor for the material doping. Nitrogen and oxygen are used for the chemical passivation layers, while aluminum is generally used for the electrodes. Now, let's focus on two key factors that make silicon such a good material for photovoltaic solar cells [2-4]. First we will see we have lots of silicon. Secondly, it turns out that the electronic band gap of silicon is close to the optimal value for the absorption of sunlight. The solar spectrum that reaches the Earth's surface is what we use to evaluate silicon's optical suitability for light absorption. Typically, we do this by using the Air Mass 1.5 spectrum, for which the light intensity has been attenuated through 1.5 times the thickness of the atmosphere. Crystalline silicon has an electronic band gap Energy Gap of 1.12 electron volts, which translates to a photon wavelength of 1107 nanometers [4-6]. Silicon has a so called indirect band gap material. This indirect band gap has the effect of forcing silicon solar cells to be much thicker than necessary in order to absorb a significant portion of the solar spectrum, which uses up more material than other materials.

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Figure1: First Generation of C-Si

2.2. Mono and Multi Crystalline Sand to Wafer Based Solar Cell

The emergence of mono- and multi-crystalline silicon, followed by a discussion of the conversion of silicon, is from its raw form to silicon of the highest purity. After further processing, the necessary crystalline structure is obtained from this high purity grade silicon dimensions in the form of wafers. According to the degree of atomic disorder, silicon can range from having an amorphous structure to having mono crystalline structure. In amorphous silicon the atoms are arranged more or less in a tetrahedral structure [7-9], but no long-range order is present. With dimensions ranging from a few millimeters to over centimeters, the single-crystalline silicon grains for multi-crystalline silicon are side by side and have distinct lattice orientations. Only 1% of the silicon is further refined to produce electronic grade silicon, the majority of which are silicone-based goods. To decrease the percentage of impurities in the silicon, a refining process is necessary. Then forms higher purity grade silicon named polycrystalline silicon. Multi-crystalline silicon wafers are cut from silicon casted ingots, resulting in lower electronic grade material.

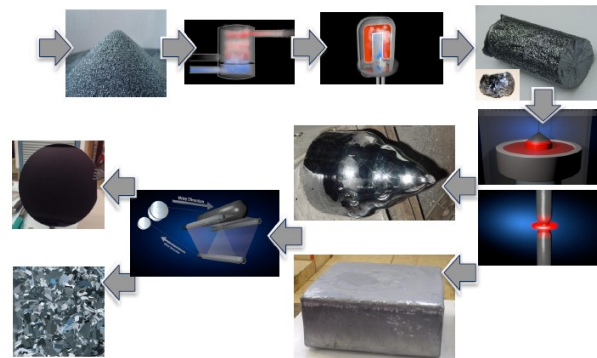


Figure 2: Silicon Wafer Processing

2.3. Design of C-Si Solar Cell

We will go through how the front surface of the solar cell is passivated as well as how specific processing methods and design factors can enhance the purity of the crystalline silicon material. We have discovered that we can define quasi-Fermi levels for electrons and holes, denoted as E_{f_n} and E_{f_p} , when surplus charge carriers are created in a semiconductor material, which causes it to lose thermal equilibrium. The mechanism is surface recombination by impurities or flaws at the front surface of the cell, and the third is

situated at the interface between metal and semiconductor, where the recombination rate of charge carriers is quite high. Another metal-silicon interface, where recombination losses might be significant, can be found at the rear contact of the solar cell. The ineffective separation of charge carriers in the wafer leads to this recombination. Efficient separation of electrons and holes can be achieved by an electrostatic field, which is for instance created by a p-n junction. While the electric field is only present in the depletion zone adjacent to the metallurgical interface, which is typically a region of a few hundred nanometers, the p-n junction is situated close to the front surface. Since the wafer is hundreds of micrometers thick, it is likely that the majority of the p-type wafer's generated electrons and holes are not affected by the electrostatic field.

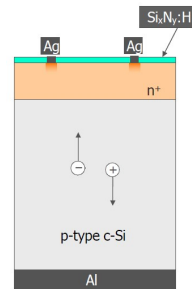


Figure 3: Back contact Design of C-Si Solar cell

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3. Thin Film Solar Cells

Thin film solar cells consume a lot less material because they are constructed from films rather than the wafers that serve as the foundation for first-generation PV. Compared to the processes utilized for crystalline silicon, thin film solar cells are considerably different [10-12]. It was anticipated that thin-film solar cells will become far less expensive than first generation solar cells. However, due to the current price decline in wafer-based solar cells, most thin-film solar cells have not yet become economically viable.

3.1. Transparent Conductive Oxide Solar Cells

The role of the TCO in a thin-film solar cell, as well as the composition and efficiency of TCOs the glass superstrate is covered with the metal electrode and semiconductor junction. Alternatively, in substrate configuration, either the substrate acts like a back contact or the back contact is deposited in the substrate. The front electrode, collecting the electrons, however only covers a very small portion of the front surface, in order to minimize shading losses. Many materials used for thin film solar cells have relatively poor lateral conductivity due to the thin film deposition techniques and growth direction of the materials.

3.2. Chalcogenide Solar Cells

Chalcogenide solar cells represent yet another subgroup of thin-film solar cells. The term chalcogenides refers to all chemical compounds consisting of at least one chalcogen anion, from group VI, and at least one or more electropositive elements. The chalcogenides are a very large group, the two most important technologies. First is cadmium telluride, which currently is the thin-film technology with the lowest demonstrated cost per Watt-peak. Materials from groups 2 and 6 are also used, as well as elements like oxygen, zinc, and aluminum, for the TCO layer in this family of chalcogenides [13-15]. The second category of chalcogenide solar cells is made up of chalcopyrite solar cells, which contain elements from groups I-III and VI. The copper-indium-gallium-di-selenide solar cells, sometimes known as CIGS, are the most prominent among these.

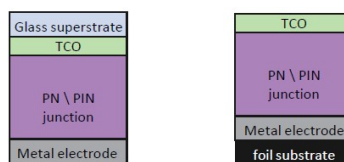


Figure 4: TCO based Solar cells

3.3. Multi Junction Solar Cells

A portion of the energy will be lost either by photons not being absorbed or through thermalization, depending on the band gap energy of the absorber. The ultimate efficiency is about 48 percent and the

Shockley Queisser limit is about 33 percent for a single junction solar cell with ideal band gap energy of 1.12 electron volts. If we were to place three P-N junctions in series, the P-layer of the top cell and the N-layer of the middle cell, for instance, would form a P-N junction themselves additionally, there are 4-terminal multi-junctions, which are mostly employed in hybrid multi-junction concepts.

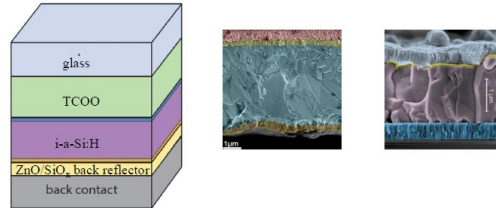


Figure 5: Multi Junction Solar cells II –VI CdTe / I-III-VI CIGS

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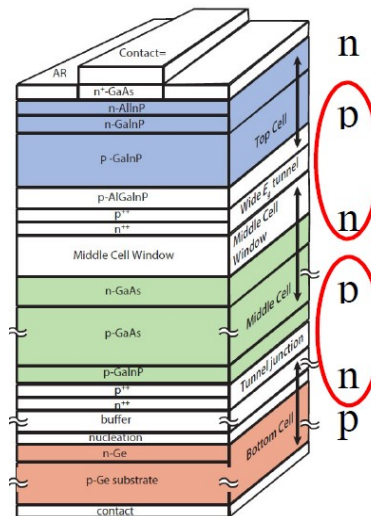


Figure 6: III – V Technologies

4. Organic PV Technologies

A characteristic of organic solar cells is their absorber material, which can be either organic molecules or conductive organic polymers based on carbon. The carbon polymers or molecules can take the shape of cyclic structures like phthalocyanine, acyclic structures like P-3-H-T, or mixed compound structures like P-C-B-M-C-61. The diverse carbon architectures result in distinct absorber materials with differing material properties. The organic solar cells can therefore be produced in a variety of colours. The ability to deposit on mechanically flexible, other thin, or transparent substrates, as well as the potential for low-cost, low-temperature production, are benefits of employing organic semiconductor materials[16].

Organic-molecule and polymer solar cells use blended heterojunction solar cells as the foundation of their traditional cell architecture. In the layers of the absorber, the donor and acceptor materials are combined. In order to avoid recombining, the excitons can now reach a donor-acceptor interface. The separated electrons travel through the acceptor layers and are collected at the electron collecting layers, abbreviated here with ECL, while the holes move through the donor material and are collected at the hole collecting layers, here abbreviated with HCL.

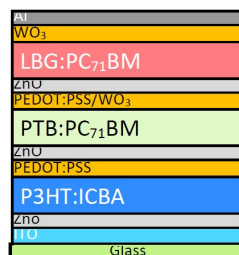


Figure 7: Organic Multi Junction Solar Cell

4.1. Perovskite Solar Cells

Perovskite solar cells experience a gradual performance decline over time, which is another major problem. The Perovskite materials can be decomposed when exposed to humidity. Under heat and light, the Perovskite phase can chemically degrade more quickly when there is water present. The structure of the lattice can be significantly modified. The lead atom and two iodine atoms form a molecule that becomes an interstitial entity in the lattice, deteriorating the electro-optical properties of the material. It has been demonstrated that halide Perovskite materials with a mixture of various cations and halide anions can significant delay or remove the chemical degradation. Perovskite solar cells have an officially verified conversion efficiency record of 19.7%. In literature, efficiencies of Perovskite solar cells are reported just over 22%. [17]. The hysteresis effect and performance deterioration caused by humidity have been considered as difficulties of the PV technology and potential solutions for the perovskites PV technology.

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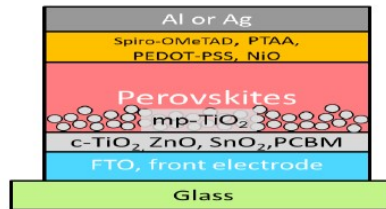


Figure 8: Perovskite Solar cell

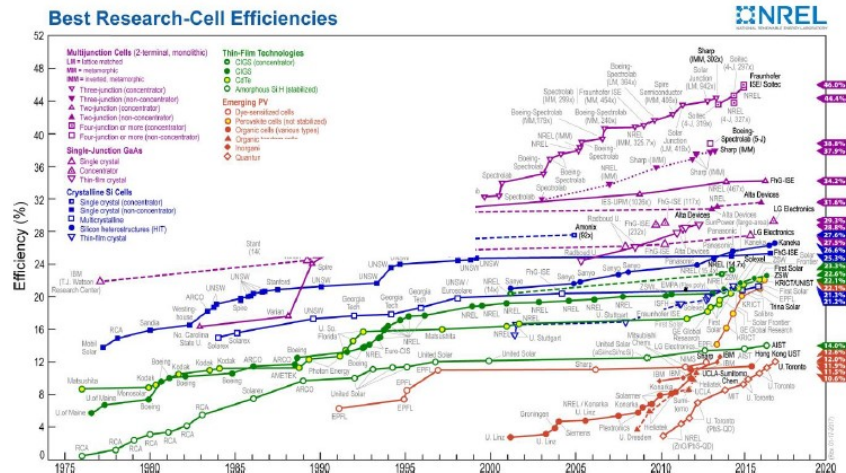


Figure 9: Best Research Cell Experience According to NREL DATA

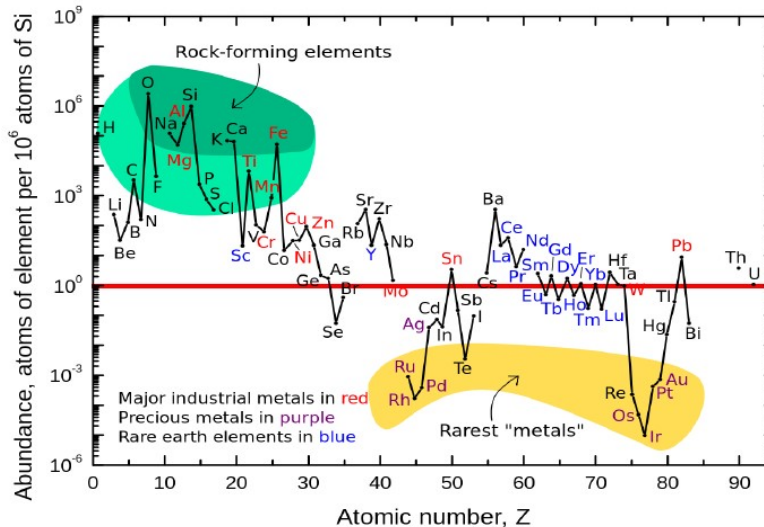


Figure 10: Abundance of elements

5. Future Trends

5.1. Hybrid PV Systems

The developed future hybrid PV multi-junction based on thin film silicon PV and organic PV the best starting efficiencies for thin film silicon multi-junction devices were examined. These figures demonstrate that switching to a triple junction will result in greater gains for thin film silicon devices. There is an absolute gain of 4.4% going from a single junction's 11.9% to a triple junction's 16.3%. On the other hand, for OPV, the increase was only slight up until 2015, increasing from 11.3% to 11.8% with a 0.5% increase [18].

It was therefore necessary to construct a hybrid multi-junction that has a top cell and/or middle cell based on a-Si: H and a bottom cell based on organic components. Three distinct varieties of amorphous silicon have been chosen for these tests. First, a single junction solar cell with an open circuit voltage of 0.98 V is constructed with a high band gap a-Si: H with a band gap of 1.73 eV. Second, an a-Si: H with a narrower band gap of 1.68 eV might result in an open circuit voltage of 0.95 V when integrated into a single junction p-i-n solar cell. Third, an a-Si: H material with the lowest band gap of the three, 1.60 eV, and an open circuit voltage of just 0.89 V. In the future, an a-Si – OPV hybrid device has developed.

5.2. Recommendations

That light can exist as photons, which are more familiar, or as Plasmon's, which spread out at the surface of a metal like gold, silver, copper, or aluminium. Stuart and Hall demonstrated that Plasmon's can also be useful in the 1990s, nevertheless. They improved the sensitivity of a basic c-Si photo detector by almost a factor 20 by adding Ag NPs of around 100 nm to its front. The PV community became interested in this, and several methods for including plasmonic structures in solar cells were researched. The semi-conductor and metal needs to be touching. The photo-generated charge carriers can, however, recombine at the Ag/Si interface created by this. As a result, at least 50% of all devices' efficiency was lost. This shows that this method calls for passivation of the metal surface, which is supposed to be quite difficult.

6. Conclusions

The record efficiency of crystalline silicon has increased from around 14% in 1975 to a record of 26.6% now held by Kaneka. The performance of CIGS and CdTe solar cells is very comparable, with a record efficiency of 22.6% for the CIGS solar cell from ZSW and 22.1% for the cadmium telluride. As we can see, research on organic Photovoltaics (PV) has only been going on for the past 15 years, with the exception of dye-sensitized solar cells. The Hong Kong UST has achieved a record efficiency of 11.5% for organic solar cells during that time and Sharp has reached a record efficiency of 11.9% for dye sensitized solar cells. Perovskite solar cells have not yet achieved a stable efficiency.

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