Solar Panels: Thorough Review and its uses

Mandavi Tiwari, Wendy High School

Abstract

Fossil fuels are non-renewable sources and cause pollution. Hence, it is mandatory to utilize another source of energy that is renewable and does not cause pollution. The energy from the sun is non-exhaustible and a better choice to make our future bright. If they can operate a massive spacecraft for so many years, they can replace fossil fuels soon. So, in this study, each aspect of solar panels has been discussed to get fundamental knowledge of solar panels.

I. Introduction

Have you ever wondered why some solar panels are black while others are blue? The hue of the solar panels totally depends on the type of silicon crystal they are made of. Solar cells convert solar energy into electrical energy. Solar cells contain multiple layers to perform this function. Usually, silicon is used in the manufacturing of solar cells, but their efficiency is very low. To boost the efficiency of solar panels, other semiconductors like gallium and germanium have been introduced to manufacture solar cells. Solar panels have seen a great improvement in their technology from the time they were invented.

II. How are solar cells made?

Solar panels are made up of small blue squares called solar cells. Solar cells may look like a single sheet, but it consists of multiple layers. The outermost layer of the solar cells is made up of glass. Since glass is an insulator, it does not allow heat to pass through it. Only photons are passed to the next layers (as glass is transparent). The next layer is an anti-reflection coating (Ethylene Vinyl Acetate). Since the silicon layer beneath the EVA sheet is a very reflecting surface, more than 30% of sunlight will be reflected in the absence of this anti-reflecting layer, which will minimize the efficiency of the solar panel. But how does this layer prevent sunlight from reflecting? As we know that reflection occurs at both surfaces in a transparent material, the reflection at the upper surface and the lower surface is aligned. But the thickness of an anti-reflecting surface is so perfect that it allows the reflected rays to bend at an angle at which the upper reflected ray and the lower reflected ray misaligned and very little reflection occurs. The EVA sheet also plays an important role in preventing water and dirt from infiltrating into solar modules as well as protecting the cell from shocks and vibrations.

Next, there are two layers made of silicon. To make these layers, first, the silicon is extracted from sand.

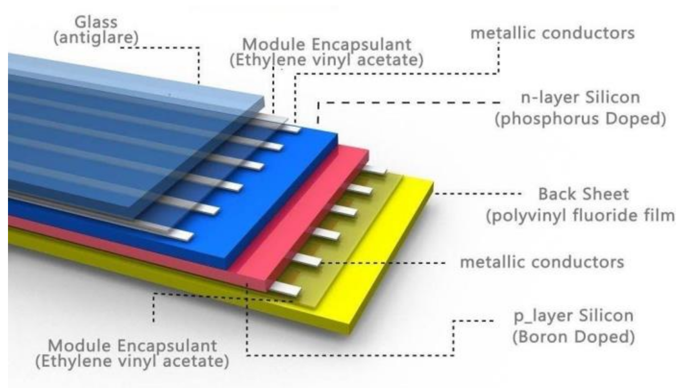

FIGURE 2: STRUCTURE OF THE SOLAR CELL

The sand from which the silicon is extracted is called silica sand or silicon dioxide which is made from crushed quartz rocks. The silica sand is then purified by extracting the unwanted oxygen and results in 99% pure silica. This process is called Carbon Arc Welding. It is then processed further to get 100% pure silica. This crystalline silica is cut into wafers to be converted into solar cells (1).

FIGURE 3: THE PROCESS OF TRANSFERRING SAND INTO A SOLAR CELL

As silicon has four electrons in its valence shell, each silicon atom is bonded with four other silicon atoms in the wafer. These bonds cannot be broken down by the sunlight. So, electric current cannot be generated here due to the absence of free electrons. To generate an electric current, some atoms of phosphorus are doped between silicon atoms (it is called N-type silicon), to get extra electrons that can move around. Since phosphorus has five electrons in the valence shell, four of them make bonds with silicon atoms, and the extra one is excited by the sunlight and jumps from the valence band to its conduction band (now the electron is free to move). The motion of these electrons is random, but electrons need to move in a single direction to produce an electric current. So, one more wafer is introduced, which is doped with boron (it is called P-type silicon), to produce electric fields. Boron has 3 valence electrons and one hole (empty orbital). Although Aluminum is at the immediate left of silicon, the Aluminum atom is not preferred as it is too large to fill the gap between silicon atoms. As the N-type silicon comes in contact with P-type silicon, the extra electrons in Phosphorus atoms fill the holes in the boron. Positively charged phosphorus atoms and negatively charged boron atoms form a barrier on the two sides (see in fig. 3)

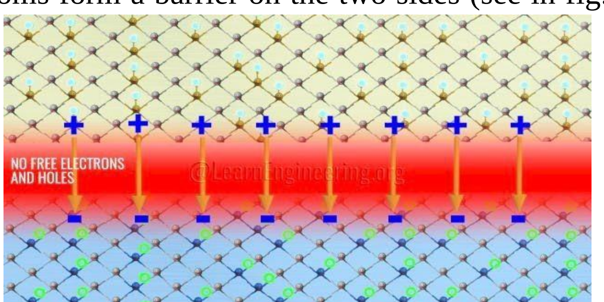

FIGURE 4: THE BARRIER FORMED BY POSITIVELY CHARGED PHOSPHORUS ATOMS AND NEGATIVELY CHARGED BORON ATOMS

forming a depletion layer (all the atoms in this layer are electrically neutral).

When the photons strike the depletion layer, the electrons in the valence band of silicon jumps to its conduction band and the electron-hole pair generates. This is known as the Photoelectric Effect which is given by the formula: $E = hv$ where, E = energy of photon, h =Planck's constant (The Planck's constant, is the quantum of electromagnetic action that relates a photon's energy to its frequency. v =frequency of light

The electric field (formed due to opposite charges on the two sides) drives the electrons towards the positive side while the holes towards the negative side and a strong potential difference are created.

Since all the free electrons are in N-type silicon (which is a semiconductor), the electrons cannot move easily in this layer. A conductor is needed for the better flow of electrons. So, the two silicon layers are sandwiched between the metal plates (the upper plate is gridded to allow sunlight to reach the underlying layers). When a bulb (or any load) is connected through a wire to these plates, the electrons start flowing in the circuit and the bulb glows (as shown in figure 4).

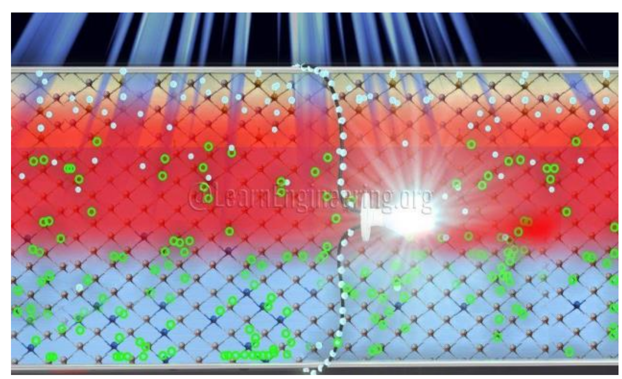

FIGURE 4: A DIAGRAM SHOWING THE ELECTRONS FLOW IN THE WIRES

Now, it is to be noted that the N-type silicon layer (being placed above the P-type silicon layer) is always a thinner P-type silicon layer so that the sunlight reaches the depletion layer.

All the solar cells are connected by silver (due to its highest conductivity) to make a solar panel. Then, solar panels are joined to make solar arrays.

III. Types of solar panels

There are three types of solar panels-

1. Monocrystalline solar panels
2. Polycrystalline solar panels
3. Thin-film solar panels

Monocrystalline- These types of panels are called "monocrystalline" because they are made up of single-crystal silicon. Silicon is formed into bars and cut into wafers to make the solar cells. Since they are made from single-crystal silicon, the electrons that generate a flow of electricity have room to move. Therefore, monocrystalline panels have the highest efficiency.

Polycrystalline- Such panels are made by the melting of many fragments of silicon to form the panels. Polycrystalline panels are also known as "multi-crystalline" because each solar cell is composed of many crystals of silicon. So, electrons do not get much freedom to move. As a result, these are less efficient than monocrystalline solar panels (2).

Thin-Film- These panels are made up of thin films of semiconductors deposited on glass, plastic, and metal. These are about 20 times thinner than the other two types of solar panels. This makes them flexible and lightweight (3).

TRAITS	MONOCRYSTALLINE	POLYCRYSTALLINE	THIN FILM
Cost	Most expensive	Less expensive	Least expensive
Colour	Black	Dark blue	Blue or black(depending on the material)
Duration	25+ years	25+ years	Unproven (expected 20 years)
Efficient	15- 23%	12- 18%	9- 14%

IV. Why Solar Panels have so low efficiency?

You might have noticed that the efficiencies of solar panels are very low. Even the best type of solar panels (that are monocrystalline solar panels) have a maximum efficiency of only 33%. What is the reason for it? William Shockley and Hans-Joachim Queisser made a discovery that solar panels with only one layer suffer efficiency limitations as they are unable to absorb solar light to its fullest. This discovery is now called the Shockley- Queisser limit. He noticed that photons from different parts of the spectrum have different natures (as shown in figure 5). (4)

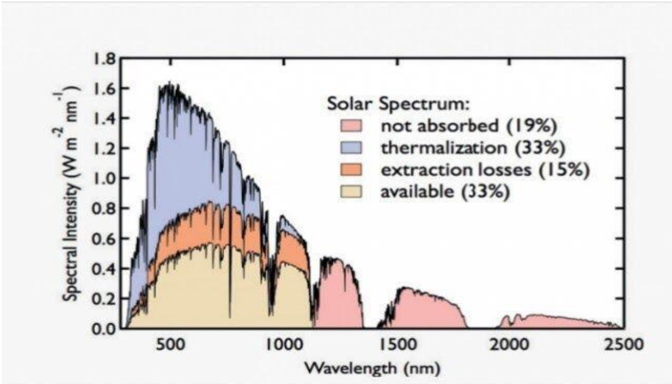

FIGURE 5: A GRAPH THAT SHOWS THE SPECTRAL INTENSITY AGAINST WAVELENGTH

It is shown in the figure that 19% of the pink color of the spectrum does not get absorbed by the solar cells. This is because the photons in this part of the spectrum have too low energy to emit the electrons (energy must be equal to or higher than the bandgap energy). 33% of the blue color (photons) is lost in thermalization (conversion of the absorbed energy into heat). This happens when photons having energy much higher than the bandgap of a semiconductor strikes the solar cells. All the energy, above the bandgap, is converted into heat. The orange color spectrum (15%) is lost due to material imperfections. All these losses contribute to lower the efficiency of the solar cells. Shockley- Queisser (5) limit led to the invention of Tandem Solar Cells which has comparatively higher efficiency.

V. Tandem Solar Cells

In Tandem solar cells (6), two cells are stacked one on top of the other, where the top cell is semi-transparent, which efficiently converts large energy photons into electricity, while the bottom cell converts small energy photons into electricity. The top cell is made up of a semiconductor that has high band energy while the bottom cell has low band energy.

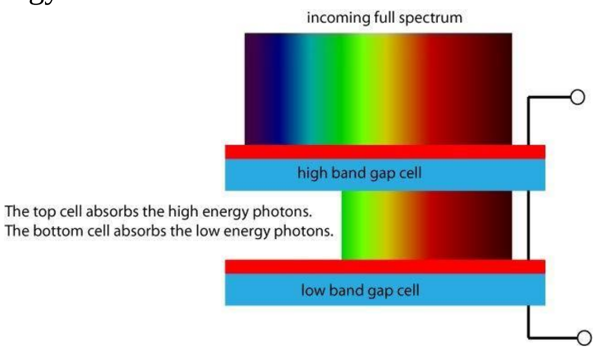

FIGURE 6: A DIAGRAM THAT SHOWS HOW TANDEM SOLAR CELLS ABSORB ENERGY PHOTONS

Let us take an example of a tandem solar cell that is the perovskite-crystalline silicon tandem. Perovskite is a material that has the same crystal structure as the mineral calcium titanium oxide. Generally, perovskite compounds have a chemical formula ABX3, where 'A' and 'B' represent cations and X is an anion that bonds to both. They are used to create semiconductors to manufacture solar cells. They are used as an alternative to silicon as they have a large bandgap.

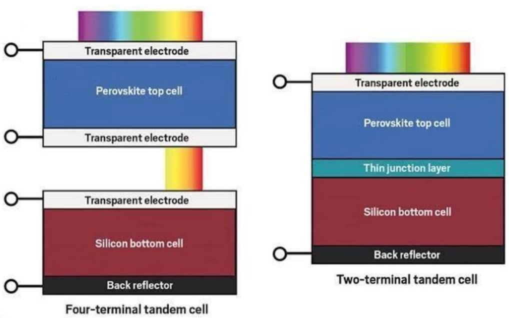

FIGURE 7: AN ILLUSTRATION OF THE DIFFERENCE BETWEEN FOUR-TERMINAL TANDEM CELL AND THE TWO-TERMINAL TANDEM CELL

In figure 7, the perovskite cell is placed above the crystalline silicon cell. The bandgap of perovskite is 1.56 eV, and the bandgap of silicon is 1.1eV. As this solar cell contains two cells with different bandgaps, the photons of different parts of the spectrum can be absorbed (1.56 eV and 1.1eV corresponds to different wavelengths of the spectrum). In this way, the efficiency of tandem will increase because more parts of the spectrum can be absorbed and converted into electricity.

VI. Multi-junction solar cells

The solar cells with one P-N junction are called single-junction solar cells while multi-junction solar cells have multiple P-N junctions of different semiconductors. Multi-junction solar cells are a type of tandem cells (with multiple cells stacked one upon another). Every cell in a multi-junction solar cell has a traditional design that includes one P-N junction. Each cell is made up of a different semiconductor (having different band gaps), with each material tuned to absorb different parts of the solar spectrum.

You can see in the figure that the blue material (GaInP) has a high bandgap so it will absorb high-energy photons (like UV and a portion of visible light of spectrum). The yellow material has a lower bandgap (1.3-1.4 eV), so it will absorb the middle portion of the spectrum. The red material has the lowest bandgap(0.67eV), so it will absorb the least energetic part of the spectrum (infrared rays). In this way, multi-junction solar cells cover the whole spectrum, and a very less portion of it is lost which makes them most efficient. The more the number of layers (p-N junctions), the higher the efficiency of the solar cell. Theoretically, a two-layer solar cell has 42% while three-layer solar has 49% efficiency.

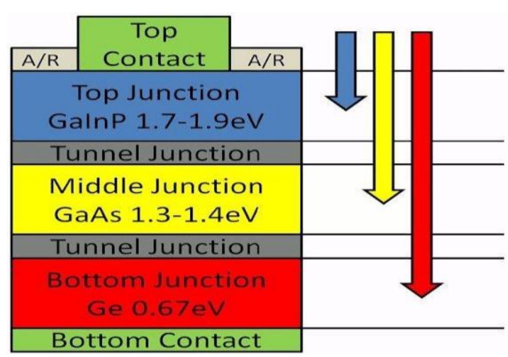

FIGURE 8: A DIAGRAM SHOWING THE PARTS OF THE MULTI-JUNCTION SOLAR CELLS

A solar cell with 5-6 layers may have an efficiency of up to 70%. Multi-junction solar cells [7] are made using materials like GaInP (gallium indium phosphide) for the top layer, GaAs (gallium arsenide) for the middle layer, and Ge(germanium) for the bottom. A tunnel junction is placed between two layers (as shown in the above figure) to allow the electrons to flow between the cells and keep the electric fields of the two cells separate. Multi-junction cells focus on gallium arsenide because it has a desirable bandgap [8]. It can better absorb high-energy photons, making it efficient and suitable for solar energy conversion. These multi-junction solar panels are used in spacecraft due to their high efficiency.

VII. Solar Panels in space

Due to the absence of atmosphere in space, sunlight is an abandoned form of energy. Solar panels have proved to be a reliable source of electricity for Spacecrafts. Until the early 1990s, crystalline silicon was used to make solar arrays for Spacecrafts. But after that period, crystalline silicon saw a replacement with Gallium Arsenide because silicon was not able to withstand excessive heat and cold and solar radiation in space.

In space, solar panels have to face extreme conditions (9). Degradation of solar panels occurs due to temperature fluctuations. When the panel is facing the Sun, the temperature reaches up to 150°C

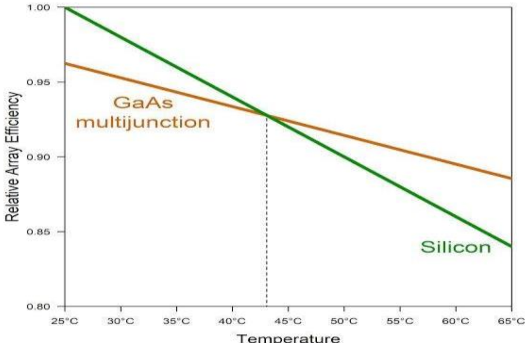

FIGURE 9: A GRAPH SHOWING THE RELATIVE ARRAY EFFICIENCY AGAINST TEMPERATURE

while the temperature is as low as -100°C when it is not facing the sun (in the shade of the Earth). Panels expand and contract due to this variation. As a result, cracks appear in the silicon crystal over the years.

Gallium Arsenide is preferred over crystalline silicon solar cells due to its higher efficiency. Gallium Arsenide is one of the main components of a multi-junction solar cell, which is used in spacecraft. Multi-junction solar panels have higher efficiency which means smaller panels will be used for the same amount of power. This will be helpful in reducing the size and weight of the spacecraft.

Moreover, gallium arsenide based solar cells degrade slowly in the space radiation environment as compared to silicon solar cells. There are four sources of space radiations:

1. Earth's radiation belt
2. Galactic cosmic rays (high energy protons and heavy ions from outside our solar system)
3. Solar wind
4. Solar flares

These radiations play a vital role in degrading the efficiency of solar panels. But the degradation rate depends on the shielding technology of solar cells. Borosilicate glass panel covering see an efficiency loss of 5-10% per year while this loss is only 1% in the case of fused silica and lead glass covering.

VIII. Conclusion

Gallium arsenide based solar cells have the following advantages over silicon solar cells:

i. Highly Efficient

Gallium arsenide has the highest efficiency than any other solar material. It can produce a larger amount of electricity per square area.

ii. Lightweight and flexible

It has high efficiency even when thin layers of gallium arsenide are used while silicon solar cells have to be thick to produce large amounts of electricity.

iii. Great resistance

Gallium arsenide solar cells can withstand solar radiation and thermal fluctuations in space. Hence, it is good for the spacecraft.

iv. Low light performance

It can work efficiently even when the light is low.

Although gallium arsenide-based solar panels are highly efficient, silicon solar panels are still used for household and commercial purposes due to the high cost of gallium arsenide solar cells.

IX. References

[1] "How Are Solar Panels Produced?" greenmatch.co.uk, 2019, https://www.greenmatch.co.uk/blog/2014/12/how-are-solar-panels-made. Accessed 03 february 2021.

[2] "Monocrystalline and polycrystalline solar panels: what you need to know." energysage.com, 2020,

[3] https://www.energysage.com/solar/101/monocrystalline-vs-polycrystalline-solar-panels/. Accessed 03 february 2021.

[4]Fazal Muhammad, Muhammad Waleed Raza, Surat Khan, Aziz Ahmed, editor. "Low Efficiency of the Photovoltaic Cells: Causes and Impacts." International Journal of Scientific & Engineering Research, vol. volume 8, no. Issue 11, 2017, p. 7. ijser.org, https://www.ijser.org/researchpaper/Low-Efficiency-of-the-Photovoltaic-Cells-Causes-and-Impacts.pdf.

[5] technology, solar. "What are tandem cells? Introduction to solar technology. Part 3." metsolar.eu, 2018, https://metsolar.eu/blog/what-are-tandem-cells-introduction-to-solar-technology-part-3/. Accessed 03 february 2021.

[6] Susumu Yoshida,. "TANDEM SOLAR CELL." United States Patent (19) Yoshida,

[7] Tapas Kumar Mallick,, Senthilarasu Sundaram, David Benson,. "Potential Environmental Impacts." Solar Energy Technologies, 2016, 23-45, sciencedirect.com, https://www.sciencedirect.com/science/article/pii/B9780128029534000032. Accessed 11 February 2021.

[8] Natalya V. Yastrebova,. "High-efficiency multi-junction solar cells: Current status and future potential." , Centre for Research in Photonics, University of Ottawa, 2007, High-efficiency multi-junction solar cells:.

[9] Takayuki Hiraia *, Masumi Higashidea , Hirohisa Kurosakia , Shirou Kawakitab , Sunao Hasegawac , Yuki Mandod , Shota Yamaguchie , and Koji Tanakac. "Re-examination of electrical failure risk on satellite's power harnesses caused by space debris impacts: simultaneous measurements of sustained discharge and plasma density." ScienceDirect, 2017, https://pdf.sciencedirectassets.com/278653/1-s2.0-S1877705817X00386/1-s2.0-S1877705817342935/main.pdf?X-Amz-Security-Token=IQoJb3JpZ2luX2VjEMj%2F%2F%2F%2F%2F%2F%2F%2F%2F%2FwEaCXVzLWVhc3QtMSJGMEQCICEkbpG16AMrHtQagsbZGnhlZ9fIo5L%2FA5K6ArnmyGZNAiAHrv8tJAz2YP%. Accessed 11 February 2021.