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A Comparative Study of Evolution Stages of Different PV Cells used in Solar Power Generation

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Abstract-Solar electric power generated via the direct conversion of solar radiation into electricity. Photovoltaic's enables humanity to make use of sunlight in a clean, everlasting, and highly versatile way. PV gets its name from the process of converting light (photons) to electricity (voltage), which is called the *PV effect*. The enormous growth in the world economy, reflecting both increases in population and rising affluence, is occurring on a planet that is no larger today than it was when we evolved some 4 million years ago. The consequences of increasing human demands on the natural systems and resources such as our fossil fuels of a finite planet are being felt in every country around the world. Photovoltaic's offer an alternative means of producing essential electric power without further endangering the delicate balance of our fragile ecosystems, and that is why the need has arrived for lowering the cost of solar energy. This can be achieved by improving the cell's efficiency.
Key Words- Module, Array, Crystalline Silicon, Amorphous Silicon, Multi Junction Cell.

I. INTRODUCTION

Today, thousands of people power their homes and businesses with individual solar PV systems. Utility companies are also using PV technology for large power stations. Photovoltaic system is composed of cells made of silicon, the second most abundant element in the earth's crust. Power is produced when sunlight strikes the semiconductor material and creates an electric current. The smallest unit of the system is a cell. Cells wired together form a module, and modules wired together form a panel. A group of panels is called an array, and several arrays form an array field. The panels are mounted at a fixed angle facing south, or they can be mounted on a tracking device that follows the sun, allowing them to capture the most sunlight. Many solar panels combined together to create one system is called a solar array. For large electric utility or industrial applications, hundreds of solar arrays are interconnected to form a large utility-scale PV system. Keeping Pace with latest technological features, a lot of work has been done in PV cell technologies to improve cell efficiency.

The paper discusses in detail the various technological evolutions in PV Cell's, and compares them for the best suited PV cell in Roof top solar power application.

Traditional solar cells are made from silicon, are usually flat-plate, and generally are the most efficient. Second-generation solar cells are called thin-film solar cells because they are made from amorphous silicon or non silicon materials such as cadmium telluride. Thin film solar cells use layers of semiconductor materials only a few micrometers thick. Because of their flexibility, thin film solar cells can double as rooftop shingles and tiles, building facades, or the glazing for skylights. Third-generation solar cells are being made from a variety of new materials besides silicon, including solar inks using conventional printing press technologies, solar dyes, and conductive plastics. Some new solar cells use plastic lenses or mirrors to concentrate sunlight onto a very small piece of high efficiency PV material.

The PV material is more expensive, but because so little is needed, these systems are becoming cost effective for use by utilities and industry. However, because the lenses must be pointed at the sun, the use of concentrating collectors is limited to the sunniest parts of the country.

II. EVOLUTION STAGES OF DIFFERENT PV CELLS

Solar PV is one the world's fastest changing technologies in the world, attracting vast amount of research and development. There are four main categories of photovoltaic cells: crystalline silicon (c-Si) solar cells, thin film solar cells (TFSC), MJ solar cells and new third generation technologies.

The first generation of solar cells, also known as silicon wafer-based photovoltaic, is the dominant technology for terrestrial applications today, accounting for more than 85% of the solar cell market. Single-crystalline and multi-crystalline wafers, used in commercial production, allow power conversion efficiencies up to 25%, although the fabrication technologies at present limit them to about 15 to 20%. The second generation of photovoltaic materials is based on the use of thin-film deposits of semiconductors, such as amorphous silicon, cadmium telluride, copper indium gallium di-selenide or copper indium sulfide. The efficiencies of thin film solar cells tend to be lower compared to conventional solar cells, around 6% to 10%, but manufacturing costs are also lower, so that a price in terms of $/watt of electrical output can be reduced. Besides, decreased mass allows fitting panels on light materials or flexible materials, even textiles. The third generation of photovoltaic cells uses organic materials such as small molecules or polymers. Thus, polymer solar cells are a sub category of organic solar cells. The third generation also covers expensive high performance experimental multi-junction solar cells which hold the world record in solar cell performance. This type has only to some extent a commercial application because of the very high production price. The approaches include dye sensitized nano-crystalline or Gratzel solar cells, organic polymer-based photo-voltaic, tandem (or multi-junction) solar cells, hot carrier solar cells, multi-band and thermo-photovoltaic solar cells. Although the performance and stability of third generation solar cells is still limited compared to first and second generation solar cells, they have great potential and are already commercialized. There are several technologies in this generation. One of them is Quantum Dot(QD) Solar Cells. These are built up of a semiconductor(silicon) coated with a very thin layer of quantum dots. Quantum dots is just a fancy name of crystals in the size range typically a few nanometres in diameter. These crystals are mixed into a solution and placed on a piece of silicon which is rotated really fast. The crystals are then spread out due to the centrifugal force.

Solar power's popularity continues to grow every year, and along with that popularity, the number of solar technologies has grown. Currently the most popular solar technologies are:

2.1 Crystalline Si solar panels
- 2.1.1 Mono Crystalline
- 2.1.2 Poly crystalline
- 2.1.3 Hybrid PV

2.2 Flexible solar cell/ Thin film solar panels
2.2.1 Dye Sensitized Solar
2.2.2 Thin Film Solar Panels
- 2.2.2.1 Amorphous Si
- 2.2.2.2 CDTE
- 2.2.2.3 CIGS

2.3 Multi Junction solar cell (M J Solar Cells)
- 2.3.1 Concentrator Photovoltaic's Multi-junction solar cells (C PV)

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2.1 Crystalline Si solar panels

2.1.1 Mono-crystalline silicon photovoltaic cells are the oldest form of photovoltaic cells and have the highest conversion efficiency among all commercial photovoltaic cells today, but they require thinly sliced silicon of high purity. They need energy and capital investment to produce monocrystalline silicon, which boosts its price. To produce mono-crystalline silicon a crystal of silicon is grown from highly pure molten silicon. This single crystal cylindrical ingot is cut into thin slices between 0.2 and 0.3mm thick- this is the basis of a solar PV cell. The edges are cut off to give a hexagonal shape so more can be fitted onto the module. These PV cells have efficiencies of 13-16% and are the most efficient type of the three types of silicon PV cell. However, they require more time and energy to produce than polycrystalline silicon PV cells, and are therefore slightly more expensive.

2.1.2 Polycrystalline silicon is also produced from a molten and highly pure molten silicon, but using a casting process. The silicon is heated to a high temperature and cooled under controlled conditions as a mould. It sets as an irregular poly- or multi-crystal form. The square silicon block is then cut into 0.3mm slices. The typical blue appearance is due to the application of an anti-reflective layer. The thickness of this layer determines the color, blue has the best optical qualities. It reflects the least and absorbs the most light. More chemical processes and fixing of the conducting grid and electrical contacts complete the process. Mass-produced polycrystalline PV cell modules have an efficiency of 11-15%. While their heat conversion efficiency falls short of mono-crystalline cells, they are inexpensive and thus are the current mainstream.

2.1.3 Hybrid photovoltaic cells are classified as PV cells that use two different types of PV technology. The Hybrid PV cell shown here is made by Sanyo and comprises a mono-crystalline PV cell covered by an ultra-thin Amorphous silicon PV layer. The advantage of these types of cells are that they perform well at high temperatures and maintain higher efficiencies (18%+) than conventional silicon PV cells. However, these cells come at a cost premium.

2.2 Flexible solar cell/ Thin film solar panels

These are photovoltaic cells produced by depositing silicon film onto substrate glass. While the cost is kept low because less silicon is used compared to crystalline types, conversion is less efficient than crystalline types. But efficiency can be improved by layering several cells and generating power from each one (multijunction); something that can only be done using thin-film types. While many variations of thin film products exist they typically have efficiency of 7-13%.

The major drawback's is that thin film technologies require a lot of space, and they are expensive but their mass production is much easier than crystalline-based modules, so the cost of mass producing thin film solar cells is relatively cheap.

Thin film technology using various photovoltaic substances, including amorphous silicon, cadmium telluride, copper indium and gallium selenide. Each type of material is suitable for different types of solar applications.

2.2.1 Dye sensitized solar Sunlight passes through the transparent electrode into the dye layer where it can excite electrons that then flow into the titanium dioxide. The electrons flow toward the transparent electrode where they are collected for powering a load. After flowing through the external circuit, they are re-introduced into the cell on a metal electrode on the back, flowing into the electrolyte. The electrolyte then transports the electrons back to the dye molecules.

Dye-sensitized solar cells separate the two functions provided by silicon in a traditional cell design. Normally the silicon acts as both the source of photoelectrons, as well as providing the electric field to separate the charges and create a current. In the dye-sensitized solar cell, the bulk of the semiconductor is used solely for charge transport, the photoelectrons are provided from a separate photosensitive dye. Charge separation occurs at the surfaces between the dye, semiconductor and electrolyte.

2.2.2 Amorphous Silicon Solar Cells

Thin film solar cells made out of amorphous silicon are traditionally used for smaller-scale applications, including things like pocket calculators, travel lights, and camping gear used in remote locations. A new process called "stacking" that involves creating multiple layers of amorphous silicon cells have resulted in higher rates of efficiency (up to 8%) for these technologies; however, it's still fairly expensive.

2.2.2.1 Cadmium Telluride Solar Cells is the only of the thin-film materials that have been cost-competitive with crystalline silicon models. In fact, in recent years, some cadmium models have surpassed them in terms of their cost-effectiveness. Efficiency levels result in a range of 9-11%.

2.2.2.2 Copper Indium Gallium Selenide Solar Cells have demonstrated the most promise with respect to their efficiency levels that range from 10-12%, somewhat comparable to crystalline technologies. However, these cells are still in the nascent stages of research and have been commercial deployed on any wide scale. That said, the technology is most used in larger or commercial applications.

2.3 Multi junction solar cell:

Solar cells containing multi junctions perform better than their single-junction counterparts with power conversion efficiencies of around 44% compared with about 29%. As their name suggests, these devices contain two or more junctions (rather than just one), each of which absorb different wavelengths of light from the Sun. For example, the junctions at the front of the cell can be made of a wider band gap material that harvests high-energy photons while more abundant lower-energy photons can be collected by a smaller-band gap material situated at the back of the cell.

Most of these cells contain an efficient transparent intermediate layer sandwiched between the junctions. This layer allows photo generated electrons and holes from neighboring junctions to pass without recombining.

The majority of multi-junction cells that have been produced to date use three layers. However, the triple junction cells require the use of semiconductors that can be tuned to specific frequencies, which has led to most of them being made of gallium arsenide (GaAs) compounds, often germanium for the bottom-, Ga-As for the middle-, and $GaInP_2$ for the top-cell.

2.3.1 Gallium arsenide substrate

Dual junction cells can be made on Gallium arsenide wafers. Alloys of Indium gallium phosphide in the range $In_{.5}Ga_{.5}P$ through $In_{.53}Ga_{.47}P$ serve as the high band gap alloy. This alloy range provides for the ability to have band gaps in the range of 1.92eV to 1.87eV. The lower GaAs junction has a band gap of 1.42eV.

2.3.2 Germanium substrate

Triple junction cells consisting of Indium gallium phosphide, Gallium arsenide or Indium gallium arsenide and Germanium can be fabricated on germanium wafers. Early cells used straight gallium arsenide in the middle junction. Due to the huge band gap difference between GaAs (1.42eV), and Ge (0.66eV), the current match is very poor, with the Ge junction operated significantly current limited.

Current efficiencies for commercial InGaP/GaAs/Ge cells approach 40% under concentrated sunlight Lab cells (partly using additional junctions between the GaAs and Ge junction) have demonstrated efficiencies above 40%.

2.3.3 Indium phosphide substrate

Indium phosphide may be used as a substrate to fabricate cells with band gaps between 1.35eV and 0.74eV. Indium Phosphide has a band gap of 1.35eV. Indium gallium arsenide ($In_{0.53}Ga_{0.47}As$) is lattice matched to Indium Phosphide with a band gap of 0.74eV. A quaternary alloy of Indium gallium arsenide phosphide can be lattice matched for any band gap in between the two.

2.3.4 Indium Gallium Nitride

Indium gallium nitride (InGaN, $In_xGa_{1-x}N$) is a semiconductor material made of a mix of gallium nitride (GaN) and indium nitride (InN). It is a ternary group III/group V direct bandgap semiconductor. Its bandgap can be tuned by varying the amount of indium in the alloy from 0.7eV to 3.4eV, thus making it an ideal material for solar cells.

2.4 Concentrator Photo voltaic Multi-junction solar cells

Concentrating photovoltaic systems use lenses or mirrors to concentrate sunlight onto high-efficiency solar cells. The approach taken by Concentrating Technologies (CT) in this module is a combination of reflective optics and the distributed location of small cells typical of refractive concentrators, thus avoiding the use of active cooling in a central receiver. This is accomplished by having a micro array of mirrors focusing the light on individual Power Conversion Units. Concentrator solar cells for terrestrial applications have shown a rapid surge in demonstrated efficiency in recent years. Multi junction cells have reached the point at which the next set of technology improvements is likely to push efficiencies over 40.6 %.

2.4.1 Linear concentrator systems collect the sun's energy using long rectangular, curved (U-shaped) mirrors. The mirrors are tilted toward the sun, focusing sunlight on tubes (or receivers) that run the length of the mirrors. The reflected sunlight heats a fluid flowing through the tubes. The hot fluid then is used to boil water in a conventional steam-turbine generator to produce electricity. There are two major types of linear concentrator systems: parabolic trough systems, where receiver tubes are positioned along the focal line of each parabolic mirror; and linear Fresnel reflector systems, where one receiver tube is positioned above several mirrors to allow the mirrors greater mobility in tracking the sun.

2.4.2 A dish/engine system uses a mirrored dish similar to a very large satellite dish, although to minimize costs, the mirrored dish is usually composed of many smaller flat mirrors formed into a dish shape. The dish-shaped surface directs and concentrates sunlight onto a thermal receiver, which absorbs and collects the heat and transfers it to the engine generator. The most common type of heat engine used today in dish/engine systems is the Stirling engine. This system uses the fluid heated by the receiver to move pistons and create mechanical power. The mechanical power is then used to run a generator or alternator to produce electricity.

2.4.3 A power tower system uses a large field of flat, sun-tracking mirrors known as heliostats to focus and concentrate sunlight onto a receiver on the top of a tower. A heat-transfer fluid heated in the receiver is used to generate steam, which, in turn, is used in a conventional turbine generator to produce electricity. Some power towers use water/steam as the heat-transfer fluid. Other advanced designs are experimenting with molten nitrate salt because of its superior heat-transfer and energy-storage capabilities. The energy-storage capability, or thermal storage, allows the system to continue to dispatch electricity during cloudy weather or at night.

III. CONCLUSION

Amongst the various existing PV technologies, c-Si is the most developed and well understood due to mainly its use in the integrated circuit industry. In addition, silicon is at present the most abundant material found in the earth's crust and its physical properties are well defined and studied. c-Si dominates the PV technology market with a share of approximately 80 % today. Crystalline solar cells make the most efficient flat solar panels due to their ability to convert the highest amount of solar energy into electricity. They have been around a long time, proving their longevity and durability. They are not hazardous to the environment. In crystalline silicon photovoltaics, solar cells are generally connected together and then laminated under toughened, high transmittance glass to produce reliable, weather resistant photovoltaic modules. PV panels made from c-Si solar cells are able to convert the highest amount of solar energy into electricity of any type of flat solar panel. Over the past years, manufacturing improvements of c-Si PV technology have focused on the decrease of wafer thickness from 400 μm to 200 μm and in parallel the increase in area from 100 cm2 to 240 cm2. The most important limitation of this technology is the cost of the silicon feedstock which renders the material cost relatively high, particularly as the silicon substrate must have a thickness of approximately 200 μm to allow the incident light to be absorbed over a wide range of wavelengths. In comparison to other solar panels the cost of c-Si solar panels is typically low around 60% of the cost of a fully installed solar power system, with installation being a significant cost component.

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