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Design of Novel Plastic Solar Cells Involving Nanotechnology and Screen-Printing Technique for Maximum Energy Harness

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Abstract-With the rapid depreciation of non- renewable sources and the counter effects caused by their extensive utilization has brought in the compulsion of turning focus towards non- renewable energy resources. With the consumption of energy being directly in proportion with the growth rate of mankind, it becomes absolutely necessary to come up alternatives that completely use non-renewable resources. With the very global demand for energy, renewable resources are fast wearing out, that too at a very alarming rate. The best solution to the above crisis is choosing a non-renewable energy source that meets the exponential demand. One of the optimal choices that is provided to us by nature is the ever available, abundant solar power. The intelligible harness of this endless resource has been providing us with a solution that is within an acceptable level. However, the production cost of these conventional silicon solar cells is quite high. Consequently, it takes quite a period of time before invested capital can be retrieved back. Hence, we propose a novel solar cell that is manufactured from plastic, using nanotechnology and screen-printing techniques. Thus, production of these plastic solar cells is quite easy and cuts down on production costs. In addition, these solar cells and panels chips in with the added advantage of being manufactured within no time and that too on a mass production scale as they are designed and produced using two latest technologies, the nanotechnology and screen-printing technique. Hence the produced plastic solar cell enables us to meet all power demands at a very low-cost affordable price margin. Thus, the proposed idea details on the intelligible design and fabrication of the novel plastic solar cells for efficient energy harness.

Keywords: Plastic (flexible) solar cells; Photovoltaic (PV); Quantum confinement; Organic- Inorganic hybrid, Stand-Alone, Grid-Connected, Conducting Polymers, P3HT, DLP (Digital Light Processing)

1. INTRODUCTION

Energy is the primary factor that improves and facilitates human lives. The improvement in standard of living directly depends upon the intelligent consumption of energy. Also, the kind of energy that is to be consumed must be chosen appropriately as several forms of energy are available. Basically, energy is available as renewable and non-renewable sources, from which mankind has chosen to utilize renewable energy sources for over more than 2 centuries. The primary reason for this choice of non-renewable energy such as fossil fuels was its ease of use, availability and the power output it produced. This consequently resulted in the depletion and acute shortage of these resources as they were all non-renewable. Also, these non-renewable energy sources could not be used fully, resulting in a lot of residue that polluted air, water and soil too Hence, now the focus has to be shifted to other alternative, the non-renewable energy resources. Out of them, our idea deals with harnessing of solar energy and producing the equivalent output like those produced by fossil fuels. Solar energy is the most abundant of all the non-conventional resources and is available throughout the year in Asian regions, unlike wind energy that is specific only to certain regions. Also, the intensity of solar energy is quite high when compared to other renewable sources.

Harnessing of this solar energy is effectively done using solar cells or their combination, the solar panel. Solar cells fall under 2 categories, namely Organic Photo Voltaic (OPV) and Inorganic Photo Voltaic (IPV). Unfortunately, both these categories trade-off their efficiencies with their stabilities. The silicon solar cell is the most efficient till date with conversion efficiencies as high as 25%.

These conventional solar cells can be classified into 2 categories namely, Organic Photovoltaic (OPV) and Inorganic Photovoltaic (IPV). The OPVs generally have higher efficiencies (about 15%), with a life-time of 20 years. They effectively produce an output current that is rated at a cost of less than 7 cents per kilo-watt hour, which in Indian rupees is approximately equal to 71.67 paisa. Such a low-cost highly efficient solar cell has its own disadvantage of having an unstable nature, because of which it does not produce a standard output at all, times.

On the contrary, IPVs are quite stable, but the investment and the output costs are quite high. The silicon photo voltaic cells generally account for the highest power conversion, approximately around 25% (14% to 19%), but their production costs are quite high. Hence, our proposed idea is to design and fabricate a solar cell out of plastic, rather than use conventional materials that are generally used for Si-solar cell manufacture.

2. CONVENTIONAL SILICON SOLAR CELLS

The following section elaborates on the commercially available solar cells that are available in the market and extensively used. These solar cells are predominantly made from silicon- a material that is abundantly available from the earth's surface. Silicon was chosen as the optimum solution as it has better carrier mobility when compared to any other element. Thus, it qualifies as an excellent semi-conductor that will produce high output when involved in photovoltaic applications.

3. CONSTRUCTION OF SILICON SOLAR CELLS

Today's silicon solar cells that are used to tap energy are basically only a few square centimeters (10cms x 10cms) in area. These solar cells generally contain a thin glass or transparent plastic coating to have protection from the environment. These solar cells can be made from a single crystal or from multiple crystals. Apparently, they are classified as Mono-crystalline and Poly-crystalline solar cells respectively.

Fig.1 Solar Cell Categorization

Each tiny solar cell is surprisingly capable of producing about 2 Watts electrical power, which is approximately equal to 15%-20% of light that is incident on it. These solar cells are generally connected in series to boost voltage or in parallel to increase current. This combination of solar cells results in the ultimate formation of a solar panel.

A solar panel or a Photovoltaic (PV) module as it is technically named, usually is fabricated with 36 interconnected solar cells, laminated by glass or plastic and confined within an aluminum frame. For more power output more than one such module may be interconnected. At the back of each solar panel, there are standardized sockets that effectively combine the individual output from each module into one final driving output. Connection of several modules constitutes a solar array. The figure given below clearly depicts the difference between a solar cell, panel and an array.

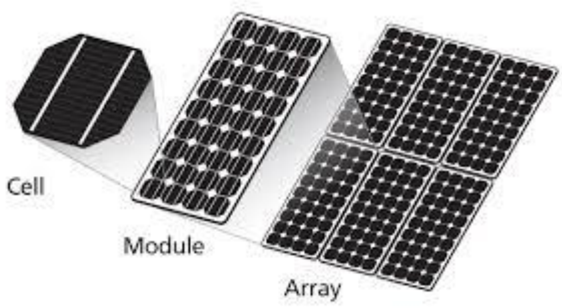

Fig 2. A Solar Cell, Solar Panel & Solar Array

Further a photovoltaic system is also categorized into 2 forms, such as Stand-Alone system and Grid-Connected system. A standalone system, as the name implies is directly wired with the required application or load. It is backed-up by a battery set, which provides current whenever the panel fails to do so. Typically, stand-alone systems are employed in remote locations, where linking to a centralized station is very expensive.

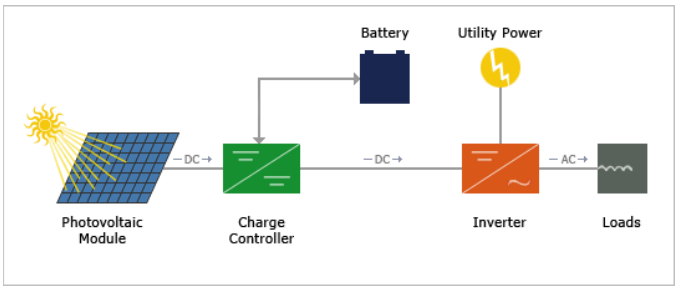

Fig 3. A Stand-Alone PV Module

On the other hand, a grid-connected system is an interconnection of several solar arrays s and hence provides public utility power. The grid-connected pv systems are either uni-directional, which supply power during mid-day peak or bidirectional, wherein the excess, unused power is fed back to the grid. Thus, a grid-connected system effectively eliminates the need for any storage batteries.

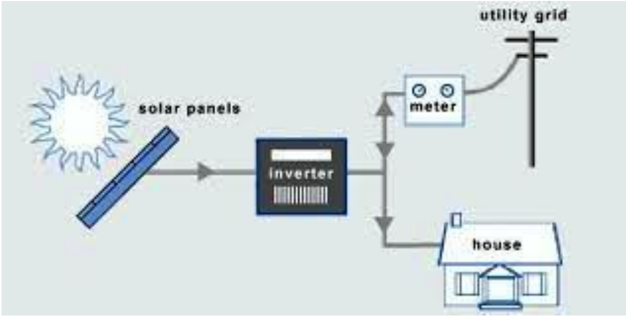

Fig 4. Grid-Connected PV System

4. WORKING

Silicon allows solar energy to penetrate easily through it, thereby enabling immediate excitation of electrons. This excitation is maximum in silicon rather than other elements, giving rise to free flow of current. In other words, energy from the sunlight breaks the covalent bondage of the valence electrons, thereby creating a sea of free electrons. These electrons are then naturally attracted towards the opposite polarity that is applied. This results in a potential difference being created, leading to flow of current. This in turn results in carrier multiplication, which gives rise to a substantial current flow at the output. The below figure illustrates the simple working of a solar panel (which is of course the combination of several solar cells), wherein the output is connected to a light load such as an electric bulb.

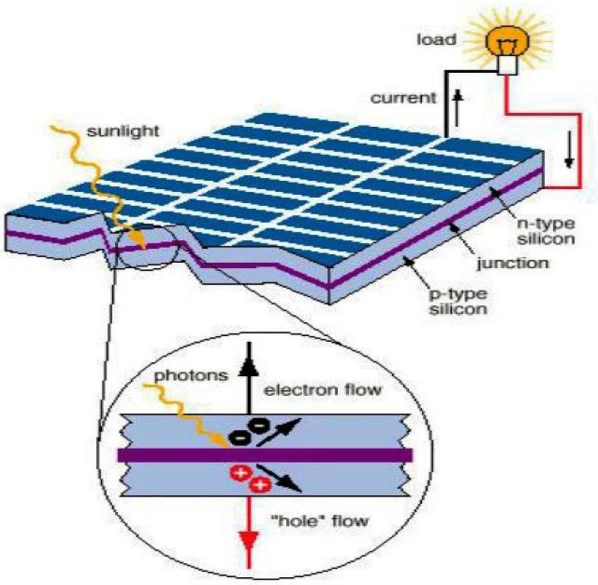

Fig 5. Si-Solar Panel Functioning Principle

Although all types of solar cells, panels or grids are fabricated and implemented successfully, there are a few set-backs that hinder the complete harness of energy. Major hindrant is the production cost that is involved in manufacturing these energy harvesting systems. The cost of each solar cell is quite high (approx 2.58 USD, i.e. 185 INR to 3.38 USD, i.e. 257 INR), which makes it difficult to install on a large scale. These panels are necessarily required to be installed at quite a large scale for efficient energy conversion. This increases the installation cost, thereby creating difficulty in recovering the invested amount within a very short span.

Another major trouble encountered when using solar cells is the variation in temperature or use in extreme temperature conditions such as military applications, space applications and so on. In both the above said cases, the cells must be highly reliable and rugged to produce exact results. The net weight of the solar panel in the case of space applications is very critical, as very heavy solar panels will hinder space craft lift-off. Also, the extra weight makes the space craft drift-off from the proposed orbit it is designed to follow.

Hence, we are in need of an alternative which reduces the investment and manufacturing cost effectively and at the same time it not trade-off efficiency to a large extent. The urgent need for solar cells for critical space applications is also very high.

Hence, we propose the use of flexible plastic hybrid solar cells that come with all required attributes that can provide a one-time solution which caters to all the high-supply as well accuracy needs.

5. PLASTIC SOLAR CELLS

The flexible plastic solar cell that is proposed is primarily manufactured from polymers with inorganic materials as blends or as composites. The novel plastic solar cell is manufactured using nanotechnology involving quantum confinement. Thus, this effect is observed when the size of the particle is too small when compared to the wavelength. Thus, there is a reduction to a nano-scale level, which in turn reduces the confining dimension. Hence, this quantum confinement increases the energy states as well as the band gap, which alter both the electrical and optical properties of the involved materials to a large extent. This results in increased flexibility, ruggedness and mainly efficiency.

6. PLASTIC SOLAR CELLS STRUCTURE

Plastic solar cells are precariously designed using nano technology to produce nano level solar cells in the form nano rods. These nano rods of cadmium selenide (CdSe) are immersed in a polymer matrix composed of P3HT (poly-3-hexylithiophene), for efficient solar energy harness. The nano rods have a thickness of about 200 nm, which can produce an output voltage of 0.7V suited for low power applications. The plastic solar cell contains a photo active layer that is sandwiched between 2 electrodes. This photo active layer is planar in nature, which increases flexibility when compared to their conventional counter parts. The nano rods in the photo active layer effectively absorb photons and generate electrons in no time. These electrons are excited by the active layer, which in turn produces electricity. In addition, the quantum confinement effect increases the efficiency by improving the electrical as well as optical properties of the material involved. The schematic of the plastic solar cell is illustrated below for reference.

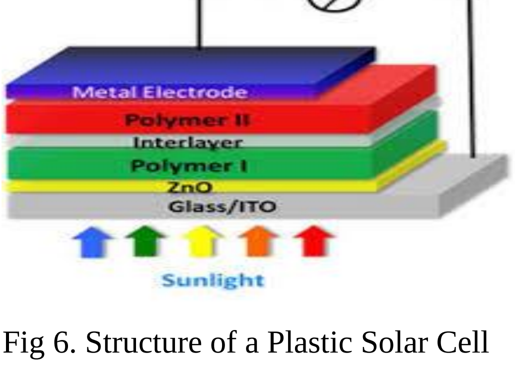

Fig 6. Structure of a Plastic Solar Cell

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7. NANO TECHNOLOGY & SCREEN-PRINTING TECHNIQUE

The proposed novel plastic solar cell is manufactured basically from nano technology as mentioned above and then compacted using screen printing technique. The nano cells that are in the form of nano rods are procured first, after which they start to harness energy through their active layers. For efficient energy conversion, it is required that all individual solar cells are wired together. To achieve this all the solar cells are required to be on the same substrate, which can be achieved only through screen printing technique.

Thus, screen printing here is employed to fabricate a polymer layer with <100mm, so that it effectively serves as a whole transport layer. This effectively increases the efficiency by around 4.3% in comparison to commercial silicon solar cells. The figure illustrated below show the production of nano rods involving nano technology for plastic solar cells. The stand-out feature of the utilizing polymer plastics is that it allows the involvement of the above said technologies to fabricate solar cells at room temperature itself. This comforts the manufacturer as no special environment is required to be set-up for plastic solar cells manufacture.

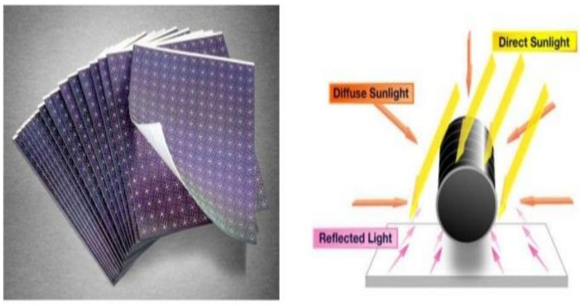

Fig 7. Nano rod in a Plastic solar cell

The next figure elucidates on the screen-printing technique that is involved in the fabricating plastic solar cells for higher energy conversion.

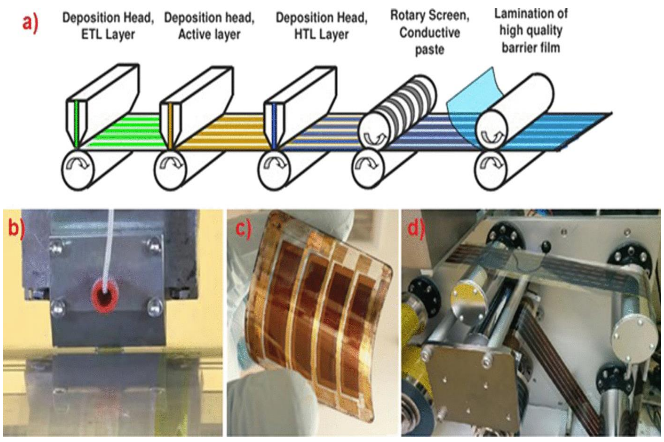

Fig 8. Screen Printing of Plastic Solar Cells

8. WORKING OF A PLASTIC SOLAR CELL

The cross section a polymer solar cell for improved efficiency is shown below for a lucid understanding of its structure and working.

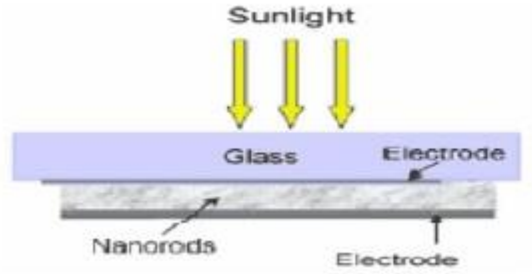

Fig 9. Schematic of a Plastic Solar Cell

The proposed hybrid solar cell contains a middle layer that is barely 200nm thick. This thin slice contains the nano rods mixed with the special plastic semiconductor, namely the,P3HT (poly-3-hexylithiophene). These rods absorb light of a specific wavelength and they generate an electron-hole pair. The nano-crystals are rod shaped enabling them to act as conductors or wires for the free electrons. A free electrons travels through the entire length of the nano rod as it is attracted towards an aluminum electrode and is then collected. The hole also referred to as the hole carrier is transferred to the plastic and then conveyed to the electrode. This creates a closed circuitry path, enabling free flow of currents in volts. This technique is highly appreciable as it is able to achieve a monochromatic conversion efficiency of 6.9%, the highest output that is ever achieved.

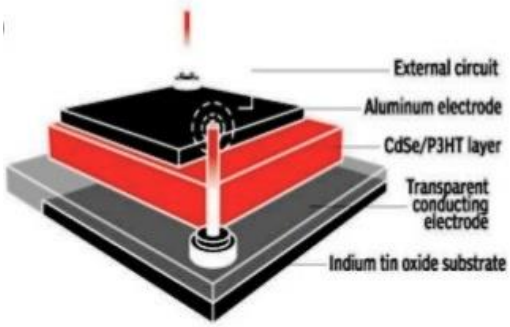

Fig 10. Operation of a Plastic Solar Cell

9. DESIGN AND MODELING OF PLASTIC SOLAR CELLS

A solar cell is basically modeled as a current source and the generated current is directly conducted to the respective terminals. Next, a P-N junction diode is connected across the output terminals to model and analyze the I-V characteristics of the solar cell. The equivalent circuit of the solar cell containing a pn junction diode is indicated below

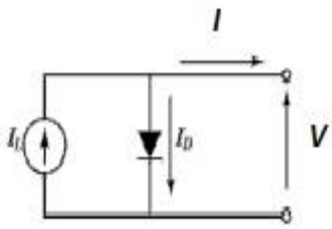

Fig 11.A single diode equivalent circuit for an ideal solar cell

The following section briefs about the mathematical modeling of the hybrid solar cells. The basic governing equations are similar to those of conventional solar cell model equations. The equations listed below are presented in a view to aid anyone for optimal modeling and to achieve a composite plastic solar cell structure.

The relationship between current and voltage that is developed in a solar cell in zero-illumination condition is given by Shockley's Equation as

$$ID = I0 \{\exp (eV / kT) - 1\}$$

Where,

e = electron charge
k = Boltzmann Constant
T = Temperature in o Kelvin
I0 = Reverse Saturation Current

Next, whenever the solar cell is exposed to sun light, the I-V curve is offset from its origin by the photo generated current IL. Thus, the current flow in fully illuminated condition is given by

$$I = IL - I0 \{\exp (eV /mkT) - 1\}$$

where,

m = Ideality Factor of the diode.

The offset is mainly caused due to the recombination effect and varies between 1 and 5.
Reverse saturation current I0 is now obtained as

$$I0 = ISC / \{\exp (eVOC /mkT) - 1\}$$

where ISC = Short Circuit Current and VOC = Open Circuit Voltage of the individual solar cell.
The temperature dependent IL is now obtained as

$$IL = IL (T1) (1 + K (T-T1))$$

where T & T1 are temperatures measured at specific instances.

Reverse bias is solar cells occur when the PV modules are partially shaded. The shaded cell now acts as the load for the circuit, offsetting the current value. This results in a mismatch, which is generally modeled by representing the avalanche breakdown effect as a dependent current source.

The mathematical model of a solar cell in reverse bias is represented as

$$I = \{IL - I0 [\exp (eV /mkT) - 1]\} M (V) - (V/RSH)$$

where RSH is the shunt resistance of the diode and M(V) is Avalanche Multiplication Factor, given by

$$M(V) = 1 / \{1- (|V|/Vb)n\}$$

Where Vb = Reverse Breakdown Voltage
n = Miller Constant

10. FLOW DIAGRAM

The following section emphasizes on how current is generated within a plastic solar cell with the help of its multi-layered structure. This can be best understood through the flow diagram that is depicted below. The multi-layered solar cell, apart from being interleaved with several polymer layers, has a solar charge controller, an input boost voltage controller for giving an optimum output even when the input intensity is very less.

All these layers are then fed to a 3-D printer which uses digital light processing technique, embeds all the above said layers into a small compact cell. The top surface of the obtained solar cell is coated with zinc-oxide (ZnO) that makes the cell insoluble to water and improves performance even on rainy and cloudy days. Next the entire structure is encased with indium-tin oxide that provides flexibility and makes the entire module light in weight.

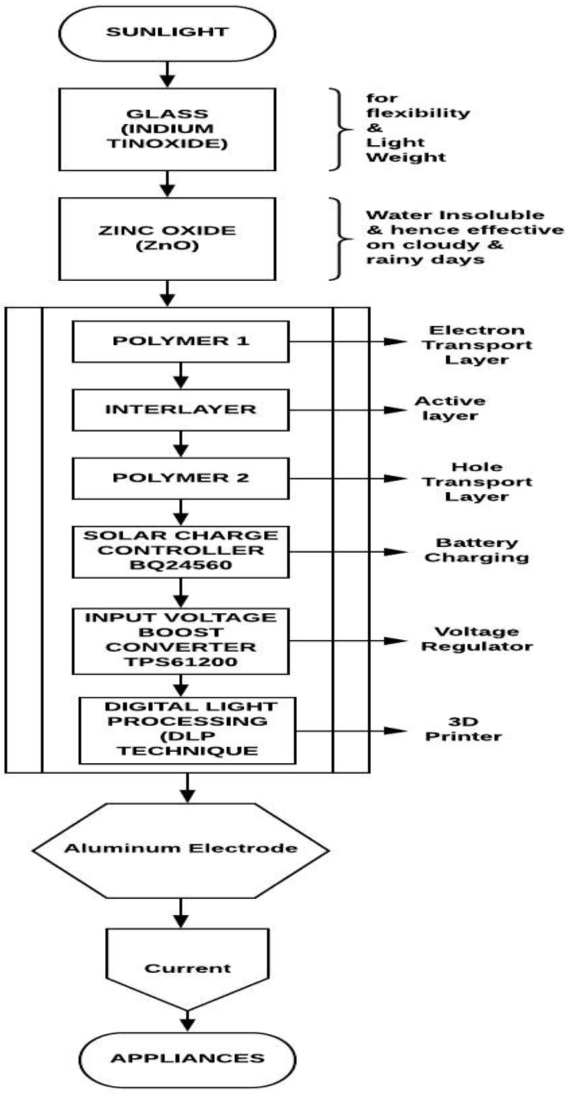

Fig 12. Plastic Solar Cell Fabrication Flow Process

11. RESULTS

The proposed plastic solar cell clearly has an edge over the conventional silicon cell. This can be proven by exposing both the solar cells to the same environment and consequently performing I-V,P-V and efficiency tests. Based upon the test results the corresponding graphs are plotted and the comparison studied. The results of the above foresaid tests are vividly illustrated in the graphs represented below.

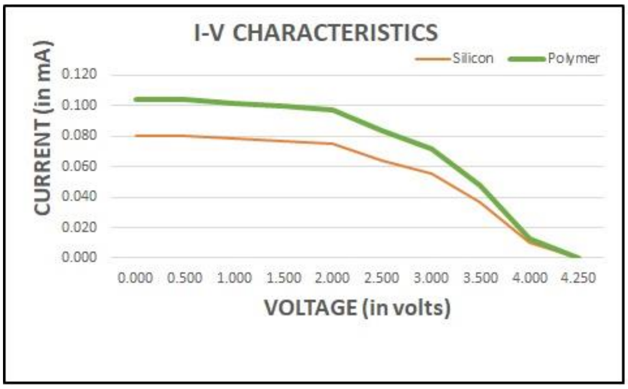

Fig 13. Current Vs Voltage Comparison Graph

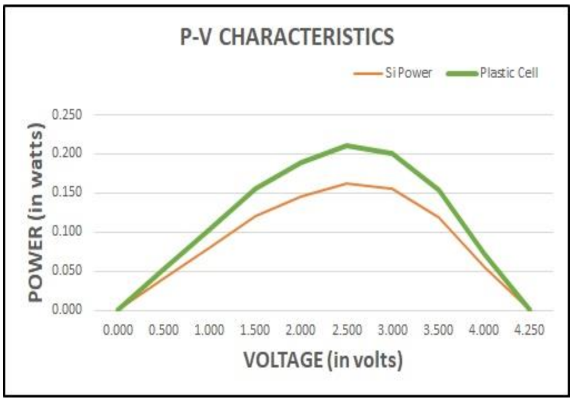

Fig 14. Power Vs Voltage Comparison Graph

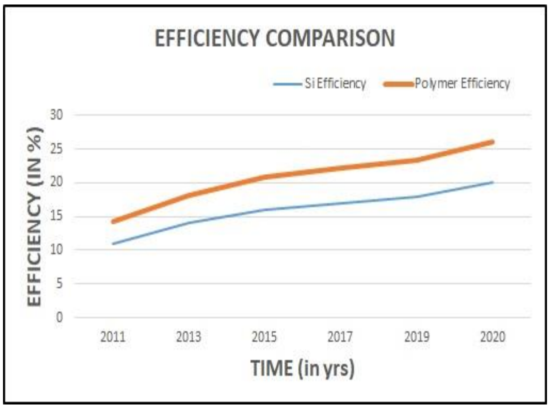

Fig 15. Efficient Utilization Comparison Graph

The above graphs depict the current-voltage, power-voltage & efficiency characteristics comparison between a silicon and polymer solar cell. All 3 graphs show the distinguishing advantage that a polymer cell holds in comparison to that of a silicon one. From the graphs it can be inferred that a plastic solar cell has approximately 30% more superiority over its silicon counter-part. The final graph indicates that the efficiency of plastic solar cells increases gradually over the years and it can be observed that its efficiency becomes more superior as time progresses by (the gap between the curves widens as years progress).

The proposed plastic solar cell offers a great number of advantages in comparison to that of conventional ones. Hybrid solar cells do not rely on silicon nor on expensive equipment's that are required to extract and fabricate it. The plastic solar cell designed is absolutely thin and can be developed as a disposable soar panel poster by stacking by several thin plastic solar sheets together. Further, these can be sprayed like paint onto any surface , thereby creating a mobile energy supply unit. The plastic solar cells are quite easily disposable and do not cause any hazards.

The primary reason for us to opt over to these plastic solar cells is that, they offer 30% more efficiency than their silicon counterparts. The plastic solar cells are much flexible and hence can even be sewn into fabric, which enhances their applications manifold. This flexibility and compactness enable us to utilize these plastic solar cells even for miniature applications. Thus, the main disadvantage of silicon solar cells that they occupy a large workspace is quite easily overcome here.

Since these are extremely easy and handy to use with a comparative high efficiency, they become extremely reliable. They can be used in critical areas for energy abstraction. Specifically, these cells are employed as the primary source of power in in satellites. Furthermore, these plastic solar cells offer much more flexibility, durability and ruggedness which make them much more superior to other solar cells. Hence, these solar cells can be used in all critical regions like space, military, marine applications etc.

The polymer coating makes these solar cells almost unbreakable and they can be used in heavy load applications also. The plastic coating provides a protection against water as well as lightning and hence can be of better employability on rainy and cloudy days when compared to silicon solar cells. In some cases, a special additive can be added on to the panel surface, which controls the folding of polymers, thereby increasing the interface between the polymers. This results in an increased energy conversion.

12. APPLICATIONS

The hybrid solar cells are very superior when compared to their silicon counterparts and thus find applications on a very wide range. These applications vary right from small house hold needs right to large scale space applications. Some exclusive applications of plastic solar cells are in some of the high technology fields such as remote lighting systems, solar electric fences, portable power supplies, power units in satellites and so on.

Fig 16. Applications of Plastic Solar Cells

13. FUTURE ENHANCEMENT

In future, the utilization of plastic solar cells will rise exponentially. The more longer these plastic solar cells are put into use, the more higher will their efficiency increase. It can be predicted that the efficiency of proposed solar cell can go as high as 50% in comparison to a conventional one. Further, all critical applications that require a trustworthy back up power will rely only on plastic solar cells. These cells will find their extensive usage in space and marine applications where very high reliability is absolutely necessary. The usefulness of these polymer solar cells will become so high that solar farms will be laid out in all nations. The installed solar farms soon will become the sole power supply to an entire region. Addition of special chemicals can make the panels more tolerant towards water droplets and hence increase the panel throughput even on a cloudy day.

Development on a nano scale will lead to integrating these solar cells right from very large equipment to miniature ones. By altering their physical properties slightly, these polymer solar cells can be made bio degradable, enabling them to disintegrate easily when they are no longer in use. Thus, these solar cells would no longer pollute or create any hassles to the surrounding environment.

14. CONCLUSION

A hybrid plastic solar cell is henceforth proposed and designed successfully. The best replacement of fossil fuels is the abundant solar energy that can harnessed to the maximum through these polymer solar cells. These cells will henceforth be widely accepted and put to use both in industries and households because of their low cost. The ease of production and their flexible structure provides us with the freedom to use these solar cells anywhere. The effective design and structure provide us with an increased conversion efficiency, making them the most preferred renewable power source. The plastic solar cell is fabricated intelligently in such a way that it will become the primary energy source for the world in near future.

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