Transparent Solar Cells as Economic and Effective Alternative in the Field of Excitonics

Anjani Mamidala, Akanksh Mamidala, Divya Sai Nemmani, P.V. Naga Prapurna

Abstract--- Energy is essential for the economic development and growth of any society. Depletion of conventional sources and growing demands of rapid urbanization and industrialization are met through effective alternate sources like solar, wind and tidal energy. Solar energy is the most prolific method of energy capture in nature through a photovoltaic (PV) packaged module. In the recent past, for commercial and residential applications, BIPV - Building integrated photovoltaics (BIPV) are developed. Transparent solar cells are integrated with the existing window panes by absorbing and utilizing unwanted light energy through windows in buildings and automobiles. Such an efficient use of architectural space can prove to be economic for operation and maintenance but calls for installation cost. These cells allow every visible photon to pass through it and absorb all the photons in the infrared and ultraviolet range but are transparent to visible light. Anti-reflective coatings on the outside surface can further increase the efficiency by reducing reflections

I. INTRODUCTION

In recent years floodgates for research have been focusing for renewable energy where solar energy has been abundant that can satisfy society's demands from household to industrial purpose. Solar panels are devices that convert sun light into electricity. Solar panels also constitute of photovoltaic cells which absorb light energy through photovoltaic effect. Some scientists call them photovoltaics which means, basically, "light-electricity."

Scientist have though for inventing solar panels which can replace every glass material used till date. This thought brought a remarking change in technology with which every mobile phone or a building can become an energy source. A transparent solar panel works in a conventional way but allows all the visible light to pass through it and absorbs the infrared and ultraviolet light.

A transparent solar cell provides an efficiency of 2% which is very less than a conventional solar cell which provides about 15-18%. But this problem can be tackled by "stacking" wherein large number of transparent solar cells can be put together which results in increasing the efficiency of solar cells. A study shows that United States produces 1.4% of their electricity through solar cells. United States alone consists of 5-7 billion square meters of glass surface which, when replaced by transparent solar panels could produce about 40% of electricity.

The challenges that we face for stacking of photovoltaic cells are cost, efficiency, and operating lifetime. Researchers are now focusing on finding materials that will overcome these challenges. Silicon was the first material that exhibited good efficiency. It is used in mono-crystalline PV cells, which are at least 6% more efficient but also more expensive than polycrystalline PV cells. However, due to the high cost of silicon, the market requires new materials and processes that can give an equivalent efficiency, while at the same time reducing costs. Therefore, researchers came up with thin film PV cells. Thin films reduce the amount of semiconductor material used to manufacture amorphous solar cells, which reduce the cost by more than half. In addition, there is the third-generation solar cell, which includes concentrators and organic solar cells such as dye-sensitised solar cells. Most solar cell applications are terrestrial. One of the main challenges that most of these applications face is the surface area needed to produce enough electricity in the solar panel, the larger the surface area is, the more sunlight a PV can harness. Hence, the idea of transparent photovoltaic cells came to solve this challenge of effectively utilising space. However, before going through transparent solar cell technologies, it is essential to understand the concept of the solar cell and dye-sensitised solar cells, because they are 2 main structures used to build most PV models. See-through solar materials that can be applied to windows represent a massive source of untapped energy and could harvest as much power as bigger, bulkier rooftop solar units, scientists report today in Nature Energy. Moving global energy consumption away from fossil fuels will require such innovative and cost-effective renewable energy technologies. Only about 1.5 percent of electricity demand in the United States and globally is produced by solar power. Highly transparent solar applications are recording efficiencies above 5 percent, while traditional solar panels typically are about 15 percent to 18 percent efficient. Although transparent solar technologies will never be more efficient at converting solar energy to electricity than their opaque counterparts, they can get close and offer the potential to be applied to a lot more additional surface area. Traditional solar cells are built in cell modules and set on a rooftop of a building for family daily life uses. However, dust, leaves and water pudding can

Manuscript received February 01, 2019

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shade PV panels hence, significantly reducing the solar energy output.

Recently, semi-transparent plastic solar cells were developed as building materials which are called the building-integrated photovoltaics (BIPV). Konarka has developed a transparent solar cell, which can be potentially built onto electricity-generating windows. Prototypes of windows were composed of solar cell between two panes of glass. With the transparent feature, the BIPV will no longer need to be confined to overhead applications. Although they can be integrated into windows, still some current-collecting grids can be clearly seen through the plastic solar cells. A semi-transparent plastic solar cell can be one-step fabricated by an electronic glue-based lamination process combined with interface modification. The concept is to stack two or more devices with different spectral responses which enable more efficient utilisation of solar energy. The device is semi-transparent, flexible and self-encapsulated. However, due to the organic nature of these solar cells, they are not as efficient and stable as silicon solar cell. A dye-based organic solar concentrator was also developed recently that can be integrated into building materials. A thin film of dye molecules deposited on glass absorb sunlight, the light is trapped and transported within the glass by total internal reflection until it is captured by solar cells mounted on the edges of the glass.

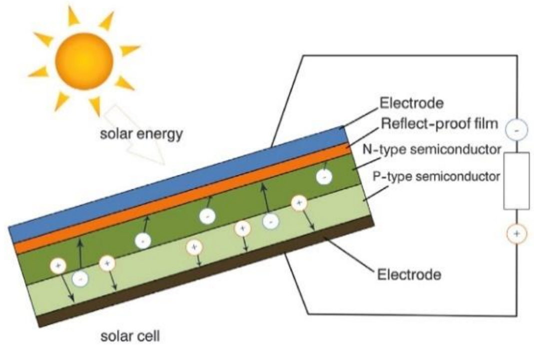

Fig. 1: (a) Cross-section of a transparent solar cell

II. PHOTO-VOLTAIC GLASS

Photovoltaic glass (PV glass) is a technology that enables the conversion of light into electricity.

To do so, the glass incorporates transparent semiconductor-based photovoltaic cells, which are also known as solar cells. The cells are sandwiched between two sheets of glass. Photovoltaic glass is not perfectly transparent but allows some of the available light through it. Buildings using a substantial amount of photovoltaic glass could produce some of their own electricity through the windows. The PV power generated is considered green or clean electricity because its source is renewable, and it does not cause pollution. In addition to energy cost savings, potential benefits from the use of photovoltaic glass include reducing the carbon footprint of facilities, contributing to sustainability and consequently, enhancing branding and public relations (PR) efforts. In environments where too much heat gets in with light, the reduced transparency can also save on air-conditioning costs. Variations have been designed for environments where more light is desired. For example, Sharp has developed a slitted solar glass product that has gaps between solar cells to enable greater light penetration. Another company, Onyx Solar, makes photovoltaic glass with a variety of options including different colours, gradient and patterns as well as double or triple-glazed products. Variance in photovoltaic efficiency and light penetration among these products enables multiple options for architectural design.

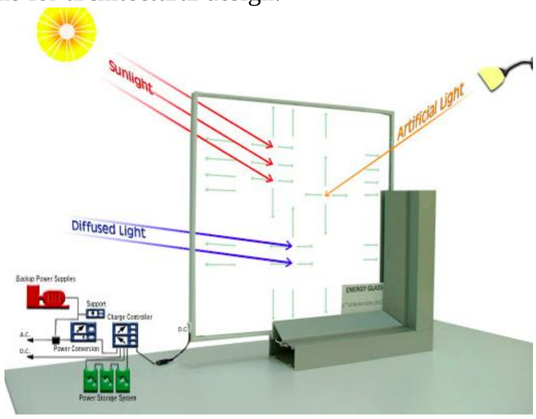

Fig. 1(b): Transmission of light energy into electrical energy

III. SOLAR GLASS

For the substrate of a thin film panel often standard glass is used, simply because it’s cheap. The superstrate cover glass has higher requirements. The cover glass needs to offer low reflection, high transmissivity and high strength. Typically, a 3.2mm thick piece of solar glass is used. The solar glass has a rough surface. This is needed, because during the lamination process, EVA needs to adhere to the glass. Completely smooth glass wouldn’t adhere well and would lead to de-lamination. The type of solar glass directly influences the amount of solar radiation that is being transmitted. To ensure high solar energy transmittance, glass with low iron oxide is typically used in solar panel manufacturing.

IV. STRENGTH OF SOLAR GLASS

Solar panels are made of tempered glass, which is sometimes called toughened glass. There are specific properties that make tempered glass suitable for the manufacturing of solar panels. First of all tempered glass is much stronger than other types of glass. Secondly, tempered glass is considered safety glass. In case it breaks, it will shatter in thousands of small pieces, that won’t be harmful. Both the strength and safety is important for the installation of solar panels.

V. DURABILITY OF SOLAR GLASS

Solar panel glass, as the front sheet of a solar PV panel, needs to provide long term protection against the natural elements. So, for the protection of PV panels tempered glass are used which are four times stronger than standard plate glass. Every pivotal piece of solar panel must be designed and installed in order to withstand extreme temperatures to dirt and water particles while guaranteeing a minimum of 25 years of power production.

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VI. TYPES OF TRANSPARENT SOLAR CELLS

There are approximately seven technologies that apply for the fabrication of transparent solar cells. The best transparency achieved through this technology is less than 80%.

1) THIN FILM PHOTOVOLTAICS(TPVs)

TPVs are the most prolific technology and is obtained via different methods. TPV is basically a thin film that has a thickness ranging from a few nanometers to tens of micrometers of active material deposited on glass in different ways. Thin film photovoltaics reduces the cost of solar cells by conserving the materials used in fabricating the cell; it is easy to deposit thin films on many different substrates, from rigid to flexible and from insulators to metals, which allows for new application. By reducing the thickness of the film, the transparency increases in some materials, such as titanium dioxide. Screen printing is the preferred method for depositing thin films and is widely used in thin film applications. Transparency is controlled by screen printing through a screen made from a mesh stretched over a frame, and its properties control the thickness and porosity of the film. Transparency is also controlled by the pressure and speed applied on the squeegee. Transparency can also be controlled by engineering the particle size, film thickness, structure of semiconductor oxide material and dye colour, which can contain different colours to absorb more light at different wavelengths.

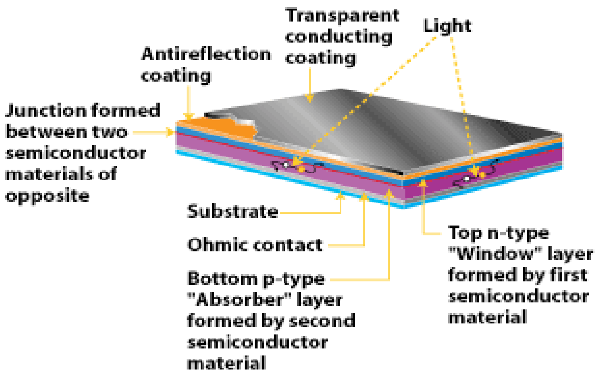

Fig. 2(a): Cross-section of thin film photovoltaics

2) NEAR INFRARED TRANSPARENT SOLAR CELLS:

As we know the main function of solar cell is to absorb photonics energy, while the main characteristics of transparency is to let photons pass through, which makes it hard to encompass both features in one material. Most of the researchers are directed towards making thin layers to achieve some amount of transparency and focus on absorbing the visible spectrum; this results in producing cells with an average transparency of less than 30% in order to maintain reasonable efficiency. So, researchers took a different direction by changing the molecules of the dye in order to absorb ultraviolet and near infrared wavelengths, instead of focusing on active layers thickness to achieve a transparent solar cell.

3) POLYMER SOLAR CELL (PSC):

To obtain an ideal photovoltaic cell the absorbing material must harness all the light in the ultra violet (UV) and near infrared (NIR) regions and allow the visible light to pass through. There are some materials with these properties such as carbon nanotubes and graphene, which are transparent conducting materials. It is inefficient to only use thesematerials to build a transparent photovoltaic. Thus, it is suggested to combine a transparent polymer solar cell with a transparent conducting material, such as silver nanowire combined with a transparent polymeric photovoltaic cell, which is non-transparent for UV and NIR light but transparent to visible light. A study reported an efficiency of 7.56% and an average transmission of 25%. In another study an alternative way was presented which used a PTB7: PC71BM polymer as well and reported a 30% transmittance and 5.6% efficiency.

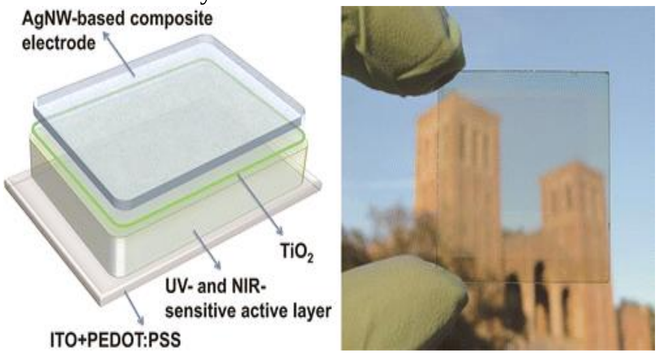

Fig. 2(b): Cross-section of polymer solar cell

4) TRANSPARENT LUMINESCENT SOLAR CONCENTRATOR (TLSC):

TLSC is based on organic salts and these take a totally different direction to realize a solar cell design with a different structure, which combines efficiency with transparency. NIR fluorescent transparent dyes are used in order to capture UV and NIR light, convert them into visible light and guide it to the edge of the glass where the solar cell is placed. TLSC is developed from luminophore blends of canine and cyanine salts and has synthesized cyanine salt-host blends with quantum yield. The transparency exhibited by TLSC is 86% and the efficiency is 0.4%.

5) PEROVSKITE SOLAR CELL:

Researchers focus on improving the semi-transparent nature of organic solar cells by utilising the absorbing material that has a lower band gap than the photons. By improving the transparency efficiency is affected. To led to find a transparent material that improves the efficiency of the cell, such as methyl ammonium lead halide perovskite. Most of the highly efficient perovskite solar cells are made out of a sandwich of a metal oxide material such as titanium dioxide and organic transport materials. Perovskites are abundant organic materials that have good electric properties suitable for solar cells, such as a high absorption coefficient, high carrier mobility, direct band gap and high stability. Most perovskite materials can achieve a power consumption efficiency of over 13%, which makes perovskite a good alternative. The semitransparent perovskite solar cell achieved a peak transmission of 77% for approximately 800nm and an efficiency of 12.7%.

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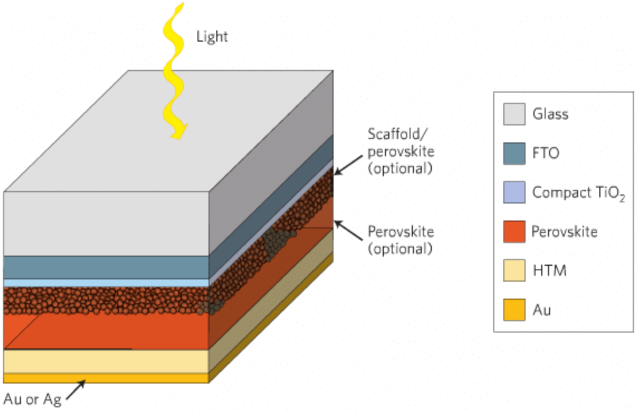

Fig. 2(c): Cross-section of perovskite solar cell

6) ELECTROPHORETIC DEPOSITION (EPD):

Electrophoretic deposition is another method for obtaining thin films. This method can be applied in two steps to deposit a thin film on fluorine doped tin oxide glass. Firstly, particles are deposited on glassy applying voltage across two electrodes, which creates an electric field. One of the electrodes acts as cathode and the other acts as anode, and they are immersed in a solvent that contains the particles. In the second step, the synthesized particles will gather and deposit on one of the electrodes, forming a thin layer of titanium dioxide. According to a study EPD electrodes shows average transmittance of 55% and an efficiency of7.1%.

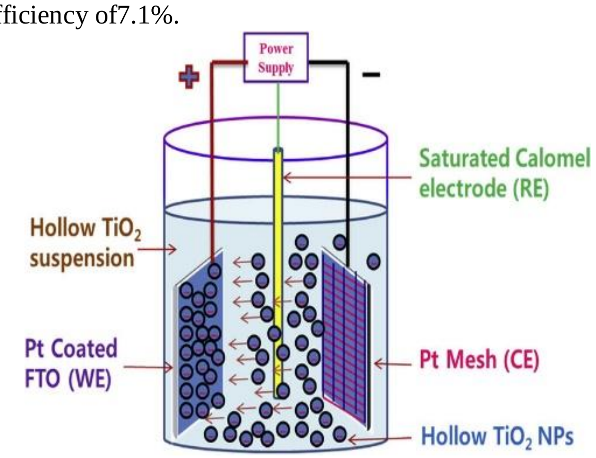

Fig. 2(d): Schematic representation of electrophoretic deposition

7) QUANTUM DOT (QD) SOLAR CELL:

Quantum dots have recently gathered attention due to their outstanding opto-electronic property. By carefully cutting QD's in different sizes, their absorption spectrum changes, which makes them suitable for solar cell application. Some heterojunction lead sulphide QD solar cells were reported to have a 9% power consumption efficiency. Additionally, lead sulphide QD has an interesting property of multi excitation generation, in which one photon excites more than one hole-electron pair. In addition, lead sulphide QD has a transparent property that can be used in semi-transparent heterojunction solar cells. By changing the thickness of the QD's, the power conversion efficiency varies from 2.04% to 3.88%, and the transmission ranges from 32.1% to 22.7%.

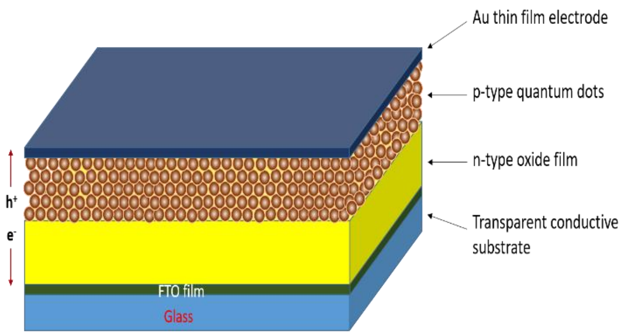

Fig. 2(e): Cross-section of quantum-dot solar cell

VII. SPECTRAL RESPONSE

The special response is conceptually similar to the quantum efficiency. The quantum efficiency gives the number of electrons output by the solar cell compared to the number of photons incident on the device, while the special response is the ratio of the current generated by the solar cell to the power incident on the solar cell. The spectral response of a silicon solar cell is very low at short wavelengths below 400nm. At intermediate wavelengths the cell approach the ideal condition. At long wavelength the response falls back to zero.

The ideal spectral response is limited at long wavelengths by the inability of the semiconductor to absorb photons with energies below the band gap. This limit is the same as that encountered in quantum efficiency curves. At these wavelengths, each photon has a large energy and hence the ratio of photons to power is reduced. Any energy above the band gap energy is not utilized by the solar cell and instead goes to heating the solar cell. The inability to fully utilize the incident energy at high energies and the ability to absorb low energies of light represents a significant power loss in solar cells.

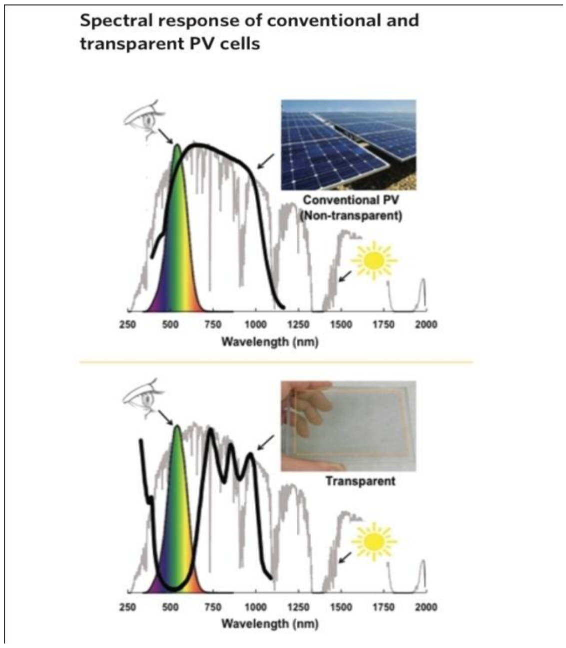

Fig. 3(a): Spectral response of conventional and transparent photovoltaic cells

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VIII. RESULTS AND DISCUSSIONS

As we get to know that by using transparent solar cells, there will be reduction in the usage of fossil fuels. By replacing all the glassware with PV cells, the power consumption will be reduced by 40%. Once they are installed, they can harness energy for a particular building for an average of 25 years. By using transparent solar cells we are shifting from solar farms to solar cities which has a number of applications. Transparent solar cells can replace the general glass ware i.e. windows, automobile glassware, cellphone glassware etc.

By using transparent solar panels, the huge equipment used for the conventional solar panels can be reduced to the size of a window.

Though the installation cost for the setup is high, there are many advantages of transparent solar panels because of their high surface area and it resembles regular glass and there will not be notable changes seen by establishing transparent solar panels. Conventional solar panels require a large setup for the consumption of sunlight and converting it into electricity. Even though the amount of electricity produced by the transparent solar panels is less compared to the conventional solar panels, the high surface area of the transparent solar panels increases the amount of electricity produced by the transparent solar panels.

IX. CONCLUSION

The rate of usage of transparent solar panels is very less when compared to that of the conventional energy sources. But, in Asian and African countries there is abundant availability of sunlight which can be trapped and used as an alternative source of energy. As Asiatic countries are highly populated, maximum amount of energy is used. So, by using transparent solar panels, energy consumption can be reduced by more than 40% which, on global scale is a very huge amount. As the non-renewable energy sources are depleting, this initiative will help us in conserving the energy and reduce global pollution which in turn reduces global warming.

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