Comparative Study of Perovskite and Silicon Solar Cell

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***Abstract*-- Photovoltaic devices that directly convert sunlight to electricity aren't new; they comprise a major section towards power generation. Various types of these energy transformers, which are known as solar cells, have been around for decades. The energy costs associated with separating tightly bound excitons (photo induced electron-hole pairs) and extracting free charges from highly disordered low-mobility networks represent fundamental losses for many low-cost photovoltaic technologies. This paper reports a low-cost, solution-processable solar cell, based on a highly crystalline perovskite absorber with intense visible to near-infrared absorptivity, that has a power conversion efficiency of 15% in a single-junction device under simulated full sunlight. This platform creates new opportunities for the development of high-efficiency and energy efficient solar cells. This paper shows that ultrafast carrier extraction is the primary reason for such high efficiencies using these perovskite-based solar cells.**

Index Terms—Silicon Solar cell, Perovskite solar cell, Conversion efficiency, IQE.

I. INTRODUCTION

Today renewable energy is the most desirable energy source of the world. Worldwide technologies have been developed for improving energy efficiency in different systems, including residential as well as commercial buildings also. It is the sun's light which is utilized either as form of heat or light directly or indirectly depending on the requirement and design [2]. Photovoltaic is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. A solar cell (also called a photovoltaic cell) is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect. It is a form of photoelectric cell (that is its electrical characteristics—e.g. current, voltage, or resistance—vary when light is incident upon it) which, when exposed to light, can generate and support an electric current without being attached to any external voltage source, but do require an external load for power consumption [3,5]. Various solar cells display varying efficiencies and varying costs such as mono crystalline silicon, polycrystalline silicon, thin film, multi junction, quantum dot, organic, polymer and dye-sensitized solar cells are being used at different levels [2,3].

High cost and environmental pollution problems urge scientists to seek new low-cost, easy-fabrication and environmentally beneficial materials for solar cells. Perovskite organic lead halides (e.g. CH3NH3PbI3) have attracted much attention due to their low cost, large absorption coefficient, and high carrier mobility. Efficiencies beyond 15% have been obtained for perovskite solar cells. Although solar cells using silicon or gallium arsenide provide efficiencies up to around 30%, improvements to production costs appear to be reaching a zenith and limit their potential to compete with fossil fuel prices. So many researchers are looking into thin film photovoltaic that may provide a bit of lower efficiencies but with much lower manufacturing costs i.e. there is a tradeoff between cost and efficiency. [1,8] Here we see how perovskite solar cells are better compared to traditional ones. In the first case we see working of single crystal silicon solar cell. However the second case comprises of the perovskite solar cell with the use of a novel photo absorber made of a lead halide perovskite (CH3NH3PbI3) that demonstrates ultrafast carrier extraction and efficiency up to 15%. This makes the architecture immediately competitive with thin film solar cells.

II. SYSTEM DESCRIPTION

The different solar cells are studied in which two different types of materials are used:Single crystal silicon cell:Single crystal silicon cells are thin wafers (300µm thick) sliced from a single crystal of p-type doped silicon. A junction is formed at one end by diffusion of the n-type impurity [2,5]. Ti-Ag electrodes are attached at front and back side, along with the use of anti-reflection coating. To increase the output solar modules are used. The principle of working can be defined as:

- Creation of electron-hole pair in the solar cell by absorbed solar radiation.
- Separation of these positive and negative charges by a potential gradient within the cell.

Energy associated with photons of sunlight is given as:

$$E= h\nu$$

Where h= Planck's constant
and v= frequency

The maximum conversion efficiency of a solar cell is given by the ratio of the maximum useful power to the incident solar radiation. Thus

$$n_{max} = \frac{I_m V_m}{I_T A_c}$$

Where $I_m V_m$ = Current and voltage at maximum power
I_T = Incident solar flux
A_c = Area of the cell
The efficiency of a solar cell may be broken down into reflectance efficiency, thermodynamic efficiency, charge carrier separation efficiency and conductive efficiency. The overall efficiency is the product of all of these individual efficiencies [6].
For an efficient cell it is desirable to have high value of conversion efficiency. For a single crystal, an efficiency value can reach upto 22%, however for commercially available modules it ranges between 12% 16%[9].

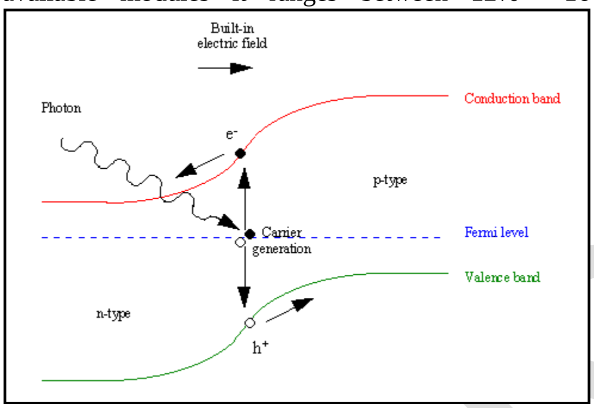


Fig 1: Principle of working of solar cell

The table showing maximum conversion efficiency of some semiconductors and specifications of single crystal module is given as follows:

TABLE I. THEORETICAL CONVERSION EFFICIENCY FOR SOME SEMI-CONDUCTORS.

Material	E_g (eV)	n_{max} (%)
Silicon	1.12	19
Gallium Arsenide	1.43	22
Cadmium Telluride	1.55	22
Cadmium Sulphide	2.42	14

TABLE II. PARAMETERS OF SINGLE CRYSTAL SILICON SOLAR MODULE.

Module size	100×50 cm
Cell size	10.4×10.4 cm
Number of cells	36
Maximum output	50 W
Maximum voltage	17.1 V
Maximum current	2.92 A
Open circuit voltage	21.6 V
Short circuit current	3.22 A
Conversion efficiency	12.8%

High-efficiency solar cells are of interest to decrease the cost of solar energy. Many of the costs of a solar power plant are proportional to the panel area or land area of the plant. A higher efficiency cell may reduce the required areas and so reduce the total plant cost, even if the cells themselves are more costly [9].

B. Perovskite Solar Cell

Perovskite-based solar cells are a hot topic in energy research and Science and their efficiency has increased from 3% to more than 16%. Semiconducting titanium dioxide or insulating aluminum trioxide film, impregnated with lead iodide perovskite ($CH_3NH_3PbI_3$) and an organic "hole-transporting material", which helps in extraction of positive charges following light absorption is used[1,7].

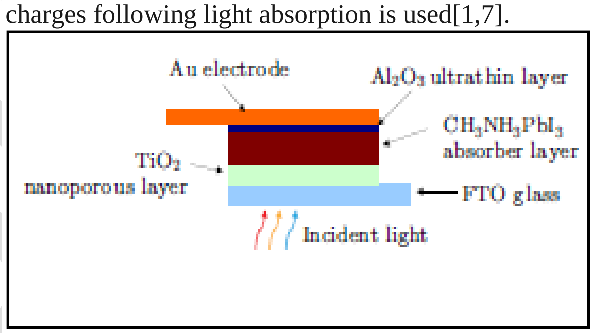


Fig 2: Principle structure of perovskite solar cell

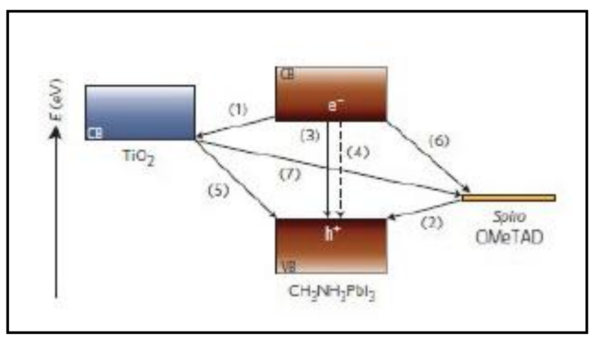


Fig 3: Principle of working of perovskite solar cell

The figure 3 describes the physical mechanisms behind the perovskite solar cell's high efficiency. A photoabsorber (the lead halide perovskite in brown) is sandwiched between two other materials – the titanium oxide (TiO_2), and the Spiro [4]. Perovskite layer acts as the valence band where all the electrons reside when no light is shining. When the perovskite absorbs light, it gives energy to an electron enough to reach the brown layer above, known as the conduction band where they can move around quickly. Once the electron is excited, it leaves behind a hole in valence band. So, if this electron in the conduction band happens to come close to the hole it left behind, the two will recombine. When this happens, there is loss of the excited electron and the potential to extract energy from the device. So, in a solar cell, prevention of recombination is required. The clever architecture used here is that the Spiro, another organic material on the other side of the perovskite, has a band close to where holes are in the valence band of the perovskite. Electrons can easily move to TiO_2, and the holes left behind can move to the Spiro, to entice electrons and holes away from each other. Titanium dioxide takes excited electrons from the perovskite and Spiro's band accept holes from the perovskite. All this happens on a subpicosecond timescale, which is very fast whereas recombination appears to take place on the microsecond timescale [10]. A solar cell must operate under conditions where extraction occurs faster than recombination, and this solar cell does so extremely well, as seen by the orders of magnitude difference of charge transfer versus recombination. This paper shows that ultrafast carrier extraction is the primary reason for such high efficiencies using this pervoskite-based solar cell.Their study shows two main dynamics i.e. firstly, that charge separation, the flow of electrical charges after sunlight reaches the perovskite light-absorber, takes place through electron transfer at both junctions with titanium dioxide and the hole-transporting material on a sub-picosecond timescale. Secondly, that charge recombination is significantly slower for titanium oxide films rather than aluminum ones. Charge recombination is a detrimental process wasting the converted energy into heat and thus reducing the overall efficiency of the solar cell so it must be avoided [7].

The lead halide perovskites constitute unique semiconductor materials in solar cells, allowing ultrafast transfer of electrons and positive charges at two junctions simultaneously and transporting both types of charge carriers quite efficiently. Improved photovoltaic performance is shown is fig.4. IQE (Internal Quantum Efficiency) is improved significantly in the whole visible wavelength region, normalized IQE in the long wavelength range is also promoted significantly, which implies that free carriers induced in deep region are collected more efficiently[8].

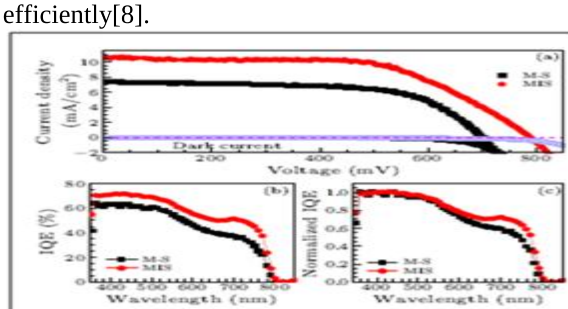
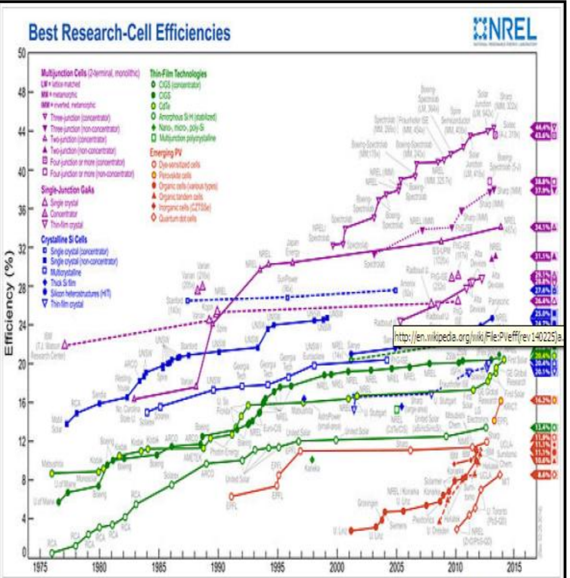


Fig. 4. (a) Illuminated (at AM 1.5 with light intensity of 100 mW/cm^2) and dark I–V curves, (b) IQE, and (c) normalized IQE of $CH_3NH_3PbI_3$ based solar cells with or without the Al_2O_3 insulating layer.

CONCLUSION

Using solar energy energy to meet the current power requirements is the need of the hour. Currently silicon solar cells are used to turn sunlight into electricity but they are expensive and require subsidies. Silicon is a poor conductor of electricity. However, by doping of phosphorous or boron conductivity can be increased. Silicon solar cells need intricate designing but they are large and bulky. They are made in enormous billion dollar clean room and high temperature fabrication facilities, which are expensive because controlling the purity of the silicon and the doping levels is not trivial. It is also energy intensive. Although prices have been coming down, fossil fuels are still so cheap it is very hard for silicon solar cells to compete [6]. Whereas the new perovskite solar cells are exotic sounding compounds that have a quite simple crystal structure called a perovskite. These solar cells are easy and cheap to make, and at same time don't reqire complicated architecture to achieve high efficiencies. Simple perovskite solar cells with efficiencies pushing upto 15-20% can be manufactured. This is major advantage, because 20% makes them competitive with existing commercial silicon solar cells while being much cheaper to make in high volumes. Perovskite is very efficient at absorbing light and uses less material to capture the same amount of energy when compared to conventional solar absorbers, meaning it could result in "dirt cheap solar power" [4]. They have the ability to control the diffusion length giving indication of how thick the photovoltaic film can be, and also there are ways to improve diffusion length by a factor of 10. The diffusion length, gives the average distance that charge-carriers (electrons and holes) can travel before they recombine. If the diffusion length is less than the thickness of the material, most charge carriers will recombine before they reach the electrodes, so only low currents are achieved. So it is necessary to have diffusion length that is two to three times as long as the thickness to collect almost all of the charges for high currents. According to the the Inhabitat report "for solar cells to be competitive with fossil fuels, the price has to drop to 50 cents per watt, using perovskite as a stand-in could drop the price of a solar cell to only 10 to 20 cents per watt, while using less material than silicon" [5].

Other advantages of perovskite solar cells include good at absorbing light, less material required to capture the same amount of sunlight, have high charge-carrier mobilities, good at transporting the electric charge created when light hits it, light weight and flexible in nature [10]. Solution processed photovoltaics incorporating perovskite absorbers have achieved higher efficiencies than thin film photovoltaics; thus establishing perovskite solar cells as a robust candidate for commercialization.



Reported timeline of solar cell energy conversion efficiencies (from National Renewable Energy Laboratory (USA))

Fig 4: Solar cell energy conversion efficiencies for different types of solar cells

REFERENCES

[1] Lee, M. M. et al. Efficient hybrid solar cells based on meso-superstructured organometal halide perovskites.

[2] "Solar Energy Fundamentals and Applications" 1st Revised Edition by H P Garg and J Prakash Published by Tata McGraw Hill.

[3] Pearce, Joshua (2002). open access "Photovoltaics – A Path to Sustainable Futures".

[4] O'Regan, B. & Grätzel, M. A low-cost, high-efficiency solar cell based on dye-sensitized colloid TiO films. Nature 353,737–740 (1991).

[5] "Light sensitive device" U.S. Patent 2,402,662(http://www.google.com/patents/US2402662) Issue date: June 1946.Pearce, Joshua (2002). open access "Photovoltaics – A Path to Sustainable Futures". Futures34 (7): 663–674. doi:10.1016/S0016-3287(02)00008-3.

[6] Oliver Morton. Solar energy: A new day dawning?: Silicon Valley sunrise. Published 7 September 2006.

[7] In Chung and co-workers. All solid state dye sensitized solar cells with high efficiency. Accepted 8 march 2012.

[8] Hui-Seon Kim, Chang-Ryul Lee, Jeong-Hyeok Im. Lead Iodide Perovskite Sensitized All-Solid- State Submicron Thin Film Mesoscopic Solar Cell with Efficiency Exceeding 9%. Published 21 August 2012.

[9] [Green, M. A., Emery, K., Hishikawa, Y., Warta, W. & Dunlop, E. D. Solar cell efficiency tables (version 39). Prog. Photovolt. Res. Appl. 20, 12–20 (2012).

[10] Chung, I. et al. All-solid-state dye-sensitized solar cells with high efficiency. Nature 485, 486–489 (2012).