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A Study the Efficiency of Developed Solar Cell Includes Perovskite Cell

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Abstract- Solar energy is the energy obtained by capturing heat and light from the Sun. The sun light required for photovoltaics is however not continuous and has daily and seasonal variations. To get continuous electricity supply there is a need for batteries to back up the energy when there is peak solar irradiation during the day time. The conventional lead acid and lithium-ion batteries are used for energy storage. Photovoltaics convert the light energy from the sun into directly usable electrical energy. The solar cells are the fastest growing alternative energy system in the past decade. There are a few critical technical and implementation issues preventing it from mass utilization. The increasing demand for renewable energy sources has driven extensive research into advanced solar technologies, with perovskite solar cells emerging as a promising candidate due to their high efficiency and low production costs. This study investigates the efficiency of a newly developed solar cell that incorporates perovskite materials. The perovskite materials which are solution-processed have accomplished amazing milestone in only a couple of years.

Keywords- Solar Cells, Perovskite, Photovoltaics, Hybrid Perovskite Solar Cells (PSCs)

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INTRODUCTION

A developed civilization must have access to a plentiful supply of energy. The world's energy usage has skyrocketed in the last two decades. The World Energy Resources Institute predicts that by 2020, the global population will have surpassed eight billion, and that the overall vital energy supply will have reached 1,7208 million tonnes of oil equivalent (Mtoe) [W. E. Council 2016]. Humanity can satisfy this demand in the long run via conventional energy sources like coal, petroleum products, etc., but doing so will have devastating effects on the environment. Overconsumption of fossil fuels, which in turn causes the release of greenhouse gases, is a major factor in the acceleration of climate change. In stark contrast to the ever-increasing need for electricity, the planet's finite supplies derived from nuclear power & fossil fuels are dwindling. Production of electricity on a worldwide scale increased from 15,500 TWh in 2000 to 22,600 TWh in 2012. Finding a replacement that makes use of renewable energy sources is, thus, obviously, required. The main advantage of assets derived from sustainable power sources is their widespread availability across different geological regions, compared to traditional resources that are limited to certain places. All life on Earth receives its energy primarily from sunlight. It can be used for a variety of purposes, and solar technology has come a long way. The use of photovoltaic cells offers hope for harnessing solar radiation and converting it into usable electricity. It is a noticeable development in the production of useable energy. When it comes to renewable energy, solar photovoltaics (PV) have become a multi-billion dollar business that is expanding at a rapid pace and continually increasing its cost-effectiveness.

SOLAR ENERGY

Human beings on earth consumes the power of approximately comparable to a steady 13 trillion watts today, the maximum of them are fossil fuels. This energy consumption will reach 30 trillion watts in 2050 as expected [Service, R. F. 2005; Potocnik 2007]. Nowadays, coal, oil, and gas have covered most of the energy demand of the world and its share is about to 75%. Definitely, the use of fossil energy encouraged in the development of industrialization and did bring lots of convenience for human societies. In recent time Beijing of China in winter days are suffering from PM 2.5 pollution, due to over excess combustion of fuels [Cao, C 2014]. To overcome these disadvantages, the expansion of alternative clean resources of energy such as hydro-energy power, biomass, wind power, and solar energy is very necessary to fulfill energy necessities without any harmful effects. Out of this solar energy might be the furthermost promising and dynamic candidate due to its unique and exceptional properties. Solar energy is the energy obtained by capturing heat and light from the Sun.

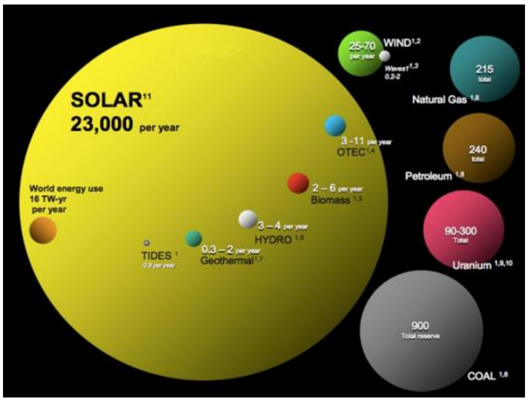

Figure 1: Numerous energy sources and global energy consumption.

PHOTOVOLTAICS

Global scenario of Photovoltaics

Photovoltaics convert the light energy from the sun into directly usable electrical energy. The solar cells are the fastest growing alternative energy system in the past decade. There are a few critical technical and implementation issues preventing it from mass utilization. The majority of the solar cells are made of silicon by high temperature processing for purification from its raw form found in sand. The doping of the silicon to make the p-n junction uses highly controlled environment which contributes to its high manufacturing cost.

The sun light required for photovoltaics is however not continuous and has daily and seasonal variations. To get continuous electricity supply there is a need for batteries to back up the energy when there is peak solar irradiation during the day time. The conventional lead acid and lithium ion batteries are used for energy storage. The inverter is used between the battery and the load. The inverter converts the battery DC into AC, but there is an associated conversion loss due to the inverter. The novel systems can use the DC directly without conversion as majority of the modern house appliances run both on DC and AC. There is also metered utility solar power, where the generated power is fed into the smart grid and the balance is reduced from the electricity bill.

The large-scale implementation of photovoltaics for power generation however has the disadvantages that the bio-life such as plants and micro-organisms in the soil is reduced. Also frequent maintenance of solar panels which include frequent cleaning is needed to ensure efficiency. The penetration of the solar panels into the energy market is less due to the fact that only 30% of the human activity needs energy in the form of electricity. The majority of the energy usage is required for heating, cooling and transportation. This calls for major shift in the technology adaptation using electrical energy instead of non-renewable fuels. In spite of all the drawbacks, due to the consistent growth and the mass manufacturing of the solar panels such as polycrystalline, monocrystalline solar cells, commercial panels with the efficiency of 15 to 18% has become possible. Major research efforts are put forward to reduce cost by reducing losses of raw materials which are cut down while processing using proton wafering. The maximum utilization of the materials is made possible by using inverted pyramid structures which improve absorption of light by using the principle of total internal reflection. The thin film technology also reduces the quantity of raw materials used and delivers higher efficiencies. The significant amount of research and development with the mass manufacturing is pushing down the cost of the solar panels and making them more economical currently than before.

PHYSICS OF PHOTOVOLTAICS

Materials for solar cell application

Materials are broadly classified as insulators, metals and semiconductors as shown in fig 2. Insulators have the valance band completely filled up with electrons. The valance band and the conduction band are separated by the forbidden energy gap of the order of 5eV magnitude and above. The electrons are bound to the atoms in the valance band with no conductivity. When photons with energies in the range of solar spectrum hit the insulators, the optical energy is insufficient to excite the electrons from the valence band to the conduction band by crossing the energy gap. Thereby, no absorption of photon takes place.

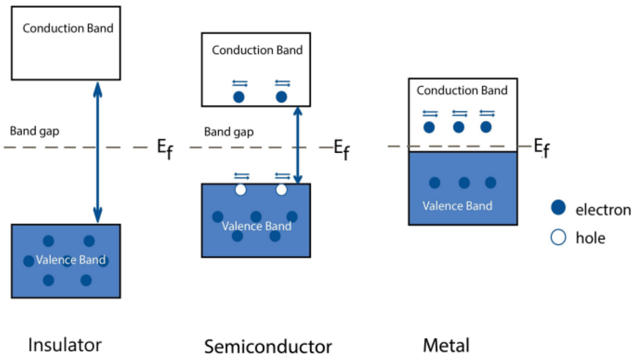

Figure 2: Material classification based on the bandgap

The metals have the highest occupied valence bands partially filled with no bandgap between VB and CB. The electrons move freely which results in high electrical conductivity. The highest occupied energy level known as the Fermi level changes with the temperature by the electron excitation due to the absorption of external energy. The photons falling over the metal gets absorbed, when the surface is rough, it acts as the black body. The metal has continuous range of allowable excitation energy available for the electron. When the photon is absorbed, the excited electron loses extra energy by generation of low energy photons in multiple steps till it losses all the excess energy and comes back to the equilibrium. The loss of the energy takes place within the terahertz scale of 10^{-12} s (Keyling et al 2000). The electron energy lost within a short time gives poor efficiency in the direct utilization for electrical energy.

Semiconductors have bandgap between the valance band and the conduction band in the range of 0.2 to 2eV. The electrons excited by the external energy such as thermal or optical means from the valance band to the conduction band, make it partially conductive. The photons falling over the semiconductors excite the electrons from the valence band to the conduction band. For the photon energy lesser than the band gap, there is no absorption of photon, similar to the insulator behavior. The photons with energy equivalent or more than the band gap is absorbed. The excess energy differences are lost in the multiple step generation of low energy photons like the metal behavior. The excited electron stays at the lowest edge of the conduction band. The excited electrons lifetime are in the order of 10^{-3}s, (Schroder 1997) which allows the extraction of electrical energy from the semiconductors.

PEROVSKITE SOLAR CELL MATERIALS

The perovskite material's chemical structure is similar to that of the calcium titanate-containing ABX3 molecule [Moreira 2009]. The cubic latticenested octahedral multilayer structures of perovskite materials have lately garnered considerable interest. Metal cations B (Pb2+, Sn2+, etc.) or halogen anion X- (Cl-, Br-, or I-, or a combination of multiple halogens) occupy the core or apex of the material, while Group A, which includes methylammonium (CH3NH3 + /MA+) or formamidinium (CH(NH2) 2+, FA+), occupies the vertex of the face-centered cubic lattice [Lin 2021]. The joining of the metal-halogen octahedral particles produces a stable three-dimensional network architecture. Figure 3 (a) [Arandiyan 2015] shows the crystal structure. In addition, Figure 3.(b) reports various perovskite solar cell efficiencies and mentions their top efficiencies to date. [Mariotti 2020] "(NREL, 2019)"

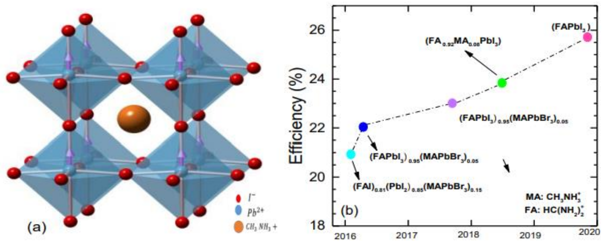

Figure 3 (a) Perovskite Solar Cell (b) A Roadmap to the Most Efficient Perovskite Solar Cell Technologies (NREL Certified, 2019).

HYBRID PEROVSKITE SOLAR CELLS (PSCs)

Solar power needs a dramatic drop in price, together with improvements in efficiency and device stability, before it can become a dominant energy source. As of now, silicon remains the PV industry standard. However, the primary obstacle to its commercialisation is its price. On the other hand, Si solar panels have become much more affordable in recent decades. In addition to this, we need look for other materials that can improve the PCE while reducing the price of solar panels. Both of these requirements can be satisfied by hybrid perovskites and metal halides. As mentioned before in this thesis, the current generation of solar cells has been replaced by the next generation, which consists of metal halide based hybrid perovskite solar cells (PSCs). One of the more recent categories of PV devices, PSCs have been instrumental in a sea change in the field, leading to unprecedented efficiency gains and the emergence of PSCs as a leading PV technology. It's not out of the question that PSCs will eventually replace all solar energy technologies. Hybrid perovskites primarily function at the intersection of chemistry, engineering, and physics; they are highly efficient because they combine inorganic and organic materials; and they are easy to work with and have a diverse range of materials. This is why they are attractive to scientists. Waldh (2016).

Metal Halide Perovskite Materials.

Originally the name perovskite had been assigned to calcium titanium oxide (CaTiO3) mineral. It was discovered in Ural Mountains of Russia by Lev Perovskite in 1839 [Mitzi 2001]. After this, its name assigned to a class of materials that crystallize in a similar structure like CaTiO3 (Fig. 4). Perovskite semiconductor materials are that mineral which has an ABX_3 crystal structure, where A & B are two cations having different sizes and X is an anion that bonds to both. The size of atoms „A" is larger than the atoms 'B'.

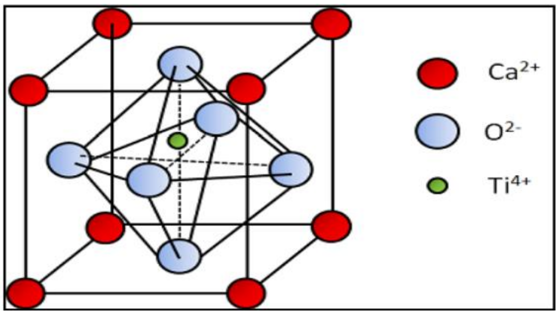

Figure 4: Crystal structure of CaTiO3

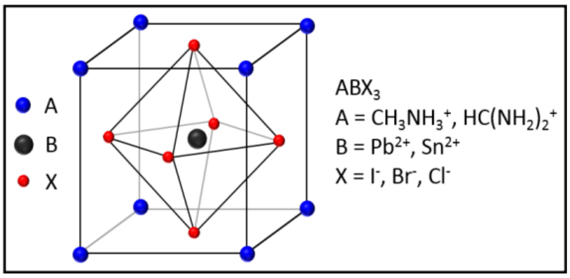

Figure 5: ABX3 perovskite structure.

On the basis of these structures, PSCs can be further divided into two parts that are inorganic perovskite and hybrid perovskite also known as hybrid PSCs and inorganic PSCs (as shown in Fig. 6).

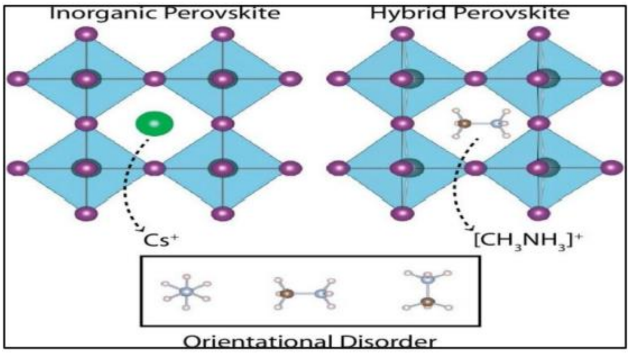

Figure 6: Inorganic perovskite and hybrid perovskite structure.

Inorganic perovskites are those in which all the atoms of ABX3 composition belongs to inorganic materials; for example, CsPbI3, Cs3Bi2I9 etc. While Hybrid perovskite materials are those in which atom A of ABX3 composition generally from the organic elements. The most widely studied hybrid perovskite material is CH3NH3PbX3 and where X belongs to halogen elements (Cl¯ , Br¯, I¯).

There are a number of diverse materials who accept this structure, with a verity of assets [Bednorz 1986]. These PSCs surpassed the PCE of 9% as well as improved the stability [Kim, H. S 2012] within one-two years after its origination (in 2009). From that, the PSCs have experienced fast development. As shown in figure 7, by 2015 their PCE has reached to 20% [Liu, M., Johnston 2013; Liu, D., and Kelly 2014]. At present, the efficiency of PSCs touches to 23.3% mark [NREL 2018].

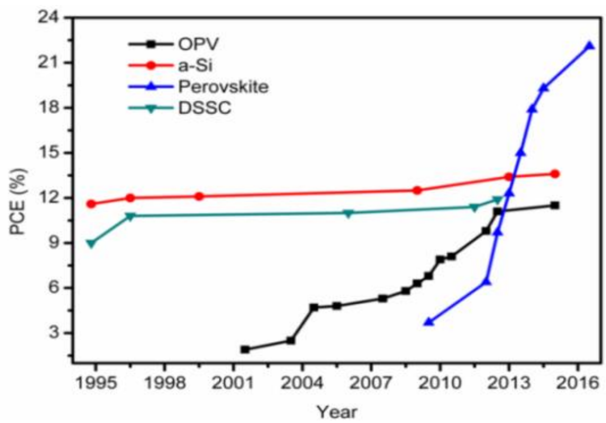

Figure 7: PCE of different kind solar cells in last twenty years.

This is further supported by the total number of publications on the topic of PSCs in subsequent years (Fig. 7).

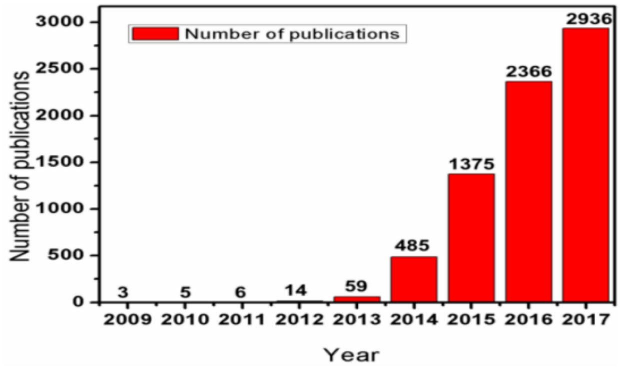

Figure 8: Annually publications compiling with the search criteria "perovskite solar cells" from 2009 to 2017.

Although, lead halide Perovskite materials show very good absorption coefficient, how good absorbing materials can be defined by absorption coefficient.

These findings have shown more rapid progress is there for PSCs compared to other PV technologies. Beside the high efficiency, they also have shown other advantages, mainly the reduced cost, and the higher value of α making them highly promising for the next-generation solar cells. The most widely studied organo-metal halide is lead halide perovskite ($CH_3NH_3PbI_3$, $MAPbI_3$) shows bandgap near to 1.5 eV ideal for the PV application and is a promising candidate of the hybrid perovskite material. However, lead compounds are very toxic in nature.

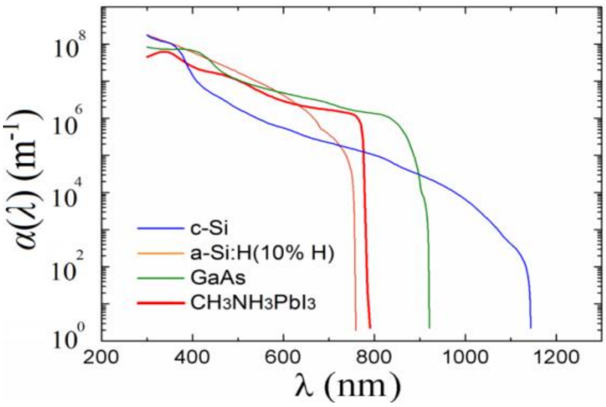

Figure 9: Absorption coefficients for different semiconductor materials used for photovoltaic applications.

Various perovskite compounds with perovskite structures for solar cells have been reported and summarized [Gratzel 2013]. Tin (Sn) as the replacement of Pb is reported by many groups. It is also a group 14 element having four electrons in the outermost cell. The reported perovskite solution $CH_3NH_3SnI_3$, $CsSnI_3$, and Cs_3Sn2_{I9} are the alternative of $CH_3NH_3PbX_3$ which has very similar structures and phase transitions [Norrman 2004] compared with the $CH_3NH_3PbX_3$. In recent years, with the improvement of fabrication expertise and procedure, the commercialization of PSCs has become an unblocked trend. Several outstanding research institution and companies have developed worldwide (see table-1) and presented promising anticipation for PSCs market.

Table1: Major progress in the PSCs by research institutions and companies

Country	Name of the company	Major progress
United Kingdom	Oxford photovoltaic Ltd	A PCE of ~ 27.3% for perovskite/silicon tandem cell.
Switzerland	Solaronix	A PCE of ~ 12% for 500 cm^2 module.
Switzerland	EPFL	A PCE of ~ 11.2% for 100 cm^2 solar panels remains stable for over a year.
Australia	GreatCell Solar Ltd	Focusing on the solar enablement of two principal substrates, glass and steel.
Japan	Toshiba	A PCE of ~ 10.5% for 25cm^2 flexible module.
China	Microquanta Semiconductor Co. Ltd	A PCE of ~ 17.9% for 227 cm^2 module.

WORKING PRINCIPLE OF PEROVSKITE SOLAR CELLS (PSCs)

PSCs were more expected to be solid-state DSCs and its working principle was assessed from the DSCs. The energy diagram for PSCs shown in Fig. 10, the working principle can be defined as follows, when a visible light was incident; the photons were absorbed and generated the exciton (e- , h+ pairs). The photon-excited electrons had moves towards the conduction band (CB), and the holes are moved towards the valance band (VB). The CB of the perovskite has higher than that of electron transport layer (ETL) (such as TiO_2, ZnO) [Kim, H. S 2012], the photon-excited electron can diffuse into the BL. Simultaneously, the photon-excited hole had absorbed by the HTL. However, sometimes the mechanism seems to be more complicated. First, the perovskite materials $CH_3NH_3PbI_3$ are direct BG semiconductor (~ 1.5 eV) having CB at ~ -3.93 eV and VB at ~ -5.43 eV. Therefore with proper alignments of CB and VB of HTL and ETL with CB and VB of perovskite material, the resulting architecture of the PSCs is expected to comparable with GaAs solar cells [Outon 2016]. However, there are still many challenges for PSCc like the quality of the perovskite films, the crystallinity of material, grain size, coverage and interfaces. High crystallinity, large grain and full coverage are considered to benefit for the high-performance PSCs. Toxicity of lead (Pb) and the stability issue of these materials are also challenging issues.

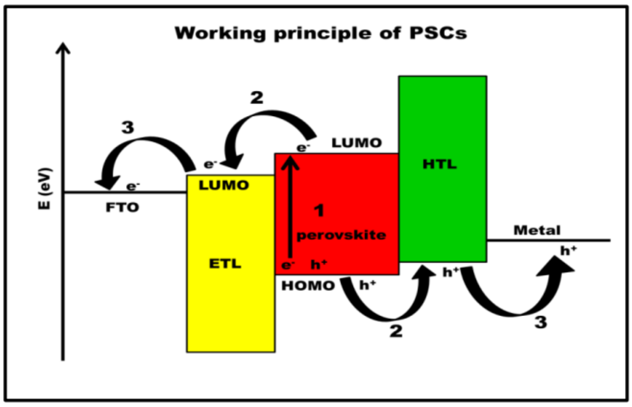

Figure 10: Schematic diagram for working principle of PSCs.

CONCLUSION

The term "solar cell" refers to an electronic device that uses semiconductors to transform the energy from the sun into electricity. Electrons move through this cell when photons, which are packets of energy, from the sun are absorbed by a semiconductor material and then released into the surrounding area, producing a hole that other electrons fill up. Because electrons move in one direction and holes in the other, current flows in the direction of the hole flow in a photovoltaic cell. The overall current is proportional to the number of electrons expelled. A stable three-dimensional network structure is formed by combining the octahedral metal halogens. PSCs exhibit a plethora of intriguing characteristics, including as magnetoresistance, spin dependent transport, and superconductivity (spintronics). Solar cells' efficiency has been dramatically enhanced with the introduction of perovskite materials.

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