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Generations of Photovoltaic's- A Review

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ABSTRACT

Much has been contributed to the literature and analysis of sustainable energy resource of solar energy. Science has developed solar cells to make most efficient use of this technology.. Silicon which is best to absorb light is largely in current use by most solar cells but inefficiencies are giving way to scientists for development of carbon nanotubes which are responsible for enhancing capabilities of current cells for light absorption. Nanotubes are difficult to arrange in suboptimal structures so till now are placed within the solar cells randomly. Nowadays solar panels are developed from a new generation mineral called perovskite, embibing the potential for solar energy conversion into cheaply available household electricity. Furthermore, is the next growing market of photovoltaic (PV) energy which is entertaining government targets to boost the solar energy production and hence reduce co2 emission. Some latest solar cell developments have been reviewed in this article.

Keywords: Black silicon, Thin film, Nanocrystal, Perovskite, Quantum dot.

1. INTRODUCTION

Nature gives an incredible supply of energy in form of sun which can fulfill all the boosting energy demands. For maximum utilisation of solar energy various solar cells are developed and still developing with great modifications and improvements. The basic principle revolves around photoelectric/photovolatic effect i.e. light + current Fig.1. To be explained it means that the natural energy source sun generates light and energy which is transformed into electric current through solar cell devices and the next aim to increase the device efficiency leads the way to different types of solar cell devices. The initial solar cell was composed of selenium in 1838.

PRINCIPLE: Solar cell comprises P (phosphorous doped silicon)-n (boron doped silicon) junction to make a sandwitch structure. P-n junction+ light illumination =power (solar cell). Increasing the surface area of solar cell in turn increases light contact and hence gives large electrical energy produced by minority charge carriers crossing the depletion layer. Technically surface concentration is approximately 10^20/cm³ . Loss is minimized by using some anti reflection coating e.g. SiO_2, Ta_2O_5 & TiO_2 etc. which boost up light absorption. Efficiency determining parameters are

1. Open circuit Voltage (Voc): $Voc = Vt^* \ln\{1 + IL/I_o\}$ (open circuit) (1)
   & $V=0$ so $Isc = - IL$ (short circuit) (2)
2. Fill Factor(FF): $(Vm\ Im) / (Voc\ IL) = Pm / Voc\ IL$ (3)
3. Efficiency: $\eta = Vm\ Im/ Pin = FF\ (Voc\ IL)/ Pin$ (4)

Band gap which is material dependent plays a vital role. Increase in Eg Band gap, leads to increment in Voc but simulataneously has a dramatical fall in IL. Materials are described as follows depicting that Gas has the lowest band gap and hence best efficiency.

A brief classification is done on basis of junction formation:

1. Heterojunction
2. Homojunction
3. Metal insulator solar cell (MIS)
4. Semiconductor insulator semiconductor (SIS)

A broad classification is done on basis of material used which will be reviewed in this paper:
Black Silicon Solar Cells,Thin Film Solar Cell (TFSC),Quantum Dot Solar Cell, Polycrystalline Solar Cell (Multi-Si),Polymer Solar Cell, Photoelectrochemical Cell (PEC), Perovskite Solar Cell, Nanocrystal Solar Cell, Multijunction Solar Cell (MJ), Monocrystalline Solar Cell (Mono-Si), Micromorph Cells (Tandem-Cell Using a-Si/μc-Si), Luminescent Solar Concentrator Cell (LSC), Hybrid Solar Cell, Gallium Arsenide Germanium Solar Cell (GaAs), Dye-Sensitized Solar Cell (DSSC), Copper Indium Gallium Selenide Solar Cells (CI (G) S), Concentrated PV Cell (CVP

and HCVP), Cadmium Telluride Solar Cell (CdTe), Toxicity of Cadmium, Buried Contact Solar Cell, Biohybrid Solar Cell, Amorphous Silicon Solar Cell (A-Si).

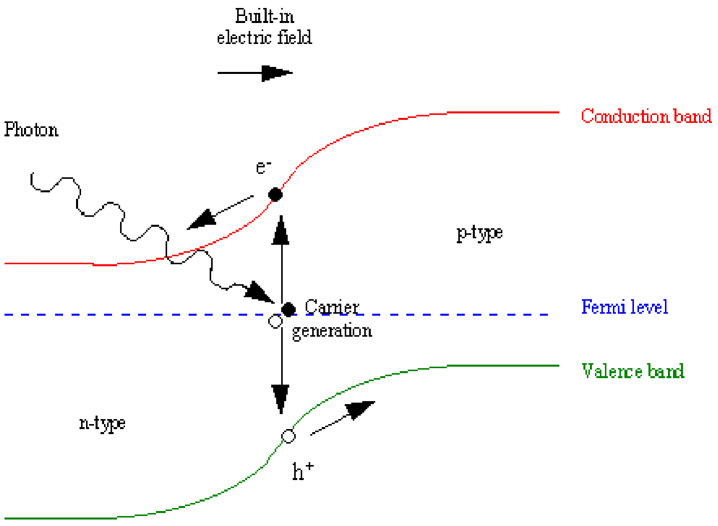

Figure1: Photoelectric/Photovolatic effect.

Table 1: Band Gap Of Different Materials

Material	Band gap
Crystalline Silicon	1.12
Amorphous Silicon	1.75
CdTe	1.45
GAs	1.42
Cds	2.4

2. DISCUSSION

Classification is done on basis of generation

A. First

composed of crystalline silicon, polysilicon, monocrystalline silicon based on photovoltaic technology and are known as conventional, traditional, wafer based cells.

B. Second

composed of amorphous silicon, CdTe and CIGS cells which forms thin film solar cells and finds use in photovoltaic power stations leading to integrated phtovolatics and small power systems. They are less costly as compared to other two and requires less construction amount and less surface area and also generates approximately same power.

C. Third

This is as till developing generation and under research and mostly are non commercial. Composed of inorganic substances and organometallic compounds. Despite of the shortcomings including less efficiency, short stability etc. this generation is trying hard to achieve goal of diminished expense and increased efficiency solar cells.

D. Fourth

They are known for organic solar cells in the 100 nanometer range with polymer binding having donor, acceptor pair, first electrode, electron transport layer, photoactive layer, hole transport layer, and second electrode. The main principle lies behind the fact that they do not have self charge is dependent on difference of electrode work function. Light absorption is done by excitons of 0.3-0.5 eV separated by heterojunctions.

3. SOME FIRST GENERATION SOLAR CELLS

E. Polycrystalline Solar Cell

Among the most ideal semiconductor material to convert solar into current polysilicon/polycrystalline silicon and monocrystalline silicon are the best options among the first generation as in Fig.2. Around the global market polysilicon accounts for more than 90%. Polysilicon is produced form metallurgical methods by chemical purification process not including silicon by electron beam smelting, low temperature alloying solidification, plasma smelting, oxidation slagging, oxidizing volatilization, vacuum evaporation, directional solidification, acid leaching etc. this is called as Siemens process as in fig. 8. The abundant crystalline silicon shows product purity is Si ≥ 6 N, non-metallic impurities P < 0.08 ppm, B < 0.3 ppm, C < 4 ppm，O < 5 ppm, Fe, Al, Ca, Ti, etc. metal impurities < 0.1 ppm; resistivity > 1 Ω·cm, minority carrier life > 25 μs, promising new avenues for solar cell materials. This leads to efficiency of 19.3%.
In the fabrication process the polysilicon large rods are broken into chunks of certain parameters and sizes and is molded into multicrystalline ingots and then recrystallised to grow single crystal. Further slicing is followed into thin silicon wafers called as crystallites and when size of crystal becomes larger than 1mm then it is referred as multicrystalline [1].

Advantages:
1. polycrystalline are less costly to buy and manufacture.
2. they are reliable as monocrystalline.

Disadvantages :
1. Less efficient as monosilicon.
2. Because of usage of multiple crystal it looks multicolored.

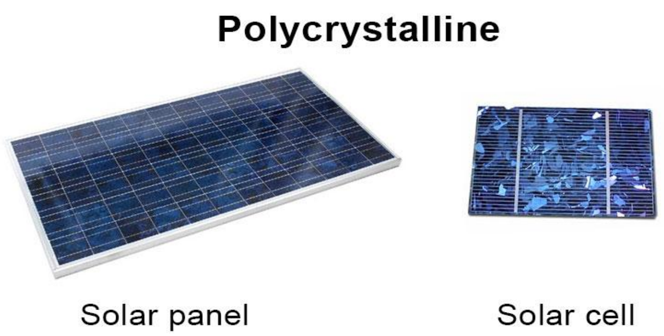

Figure2: Solar panels.

F. Black Silicon Solar Cells

Conceptually these cells share similarity with first generation crystalline silicon with the striking difference of black color which has the tendency to absorb more sunlight. Hence this property is made responsible to generate more photoelectric current. Explained by fig. 2 this process can be understood in the same manner as of black body.

Technically black silicon is prepared by adding inverted nanoscale needles (needles point in upward direction away from silicon substrate) through dry and wet etching which have a dense network on top of silicon referred in fig.3. and this slight modification makes it greatly less reflective. Moreover antireflection coatings are not required and has realized increase in efficiency > 18% and decrease in reflectivity <1%. All this process facilitates diminished loss due to surface recombination and simultaneously creates emitter and front side texture[2].

For black silicon fabrication a laser process is followed in fig.3 and fig.4, where by using optical laser pulse shaping equipment minimum damage to crystal is observed during laser silicon interaction. Further the process includes, evaporation of front contacts, deposition of screen printed rear contacts leading to emitter formation.Occasionally electron recombination with silicon atom results in energy wastage depending upon the surface area of dark silicon and hence fee conducting electrons are lost. This problem was handled and efficiency was increased to 22.1%.

Different ways for black silicon preparation are metal-assisted chemical etching (MACE), electro- chemical etching, plasma dry etching and laser irradiation.

Advantages-
1. Less crystal damage
2. Less recombination loss
3. Fabrication process steps reduced.
4. High short circuit current= 38mA/cm2 < Jsc < 42mA/cm2

5. No AR coating

Disadvantages- Efficiency progress is disturbed by carrier recombination.

Figure 3: Crystalline silicon converted to Black Silicon: absorbing more sunlight.

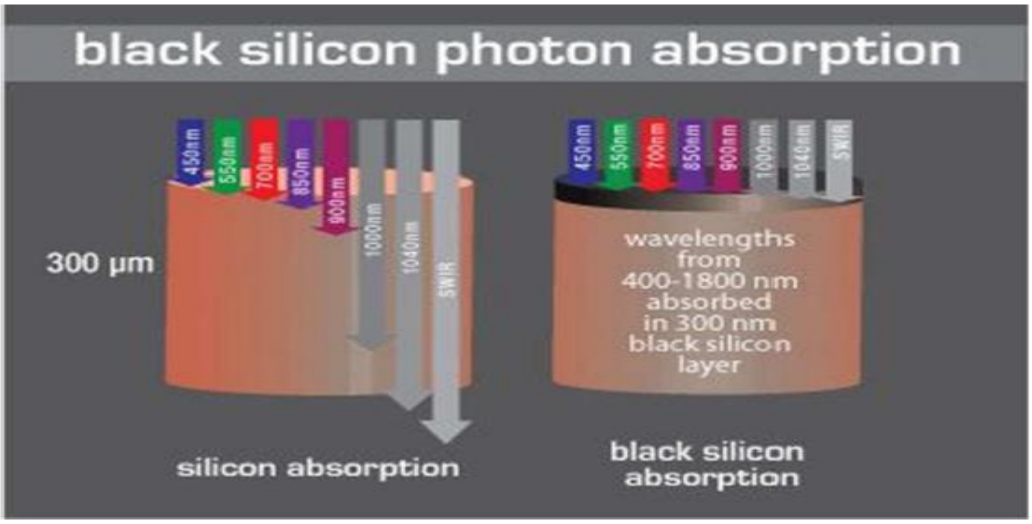

Figure 4: Sunlight absorption in black silicon.

4. SECOND GENERATION SOLAR CELLS

G. Thin Film Solar Cells

It is defined as solar cell belonging to second generation composed by one or more layers which are deposited on a silicon substrate. The TF is in range of nanometers to ten times of micrometers and needs to be of photovolataic material like CdTe, CIGS, a-Si, TF-Si. When compared to thin film in 1G of 200 micrometer, TFSC are more thinner and hence becomes an outstanding performance of TFSC as when compared to 1G as in fig.5.

Future of TF technology promises 3G PV cells in fig.5 i.e. micromorph and perovskite solar cells, quantum dot, copper zinc tin sulfide, nanocrystal, organic, dye-sensitized, polymer solar cells [3].
Applications:

1. integrated photovolataic
2. laminated windows apply nowadays semitransparent PV glazing
3. the largest power stations of the world require rigid TFSC i.e. sandwitching two glass panes.

Advantages:

1. East synthesis and preparation
2. boosted absoption efficiency of 21% by usage of cadmium telluride and copper indium
3. gallium diselenide.
4. cheaper

Disadvantage:

1. Less efficient as commercial c-Si.

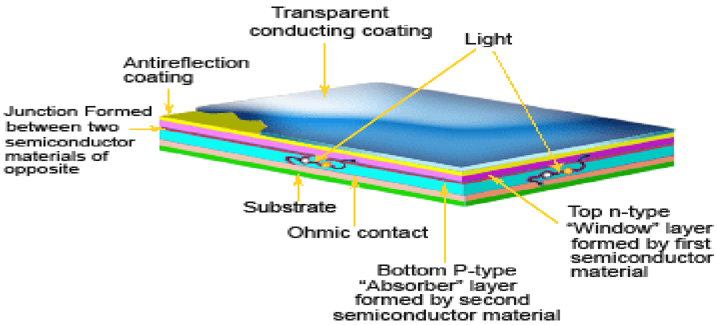

Figure 5: TFSC structure

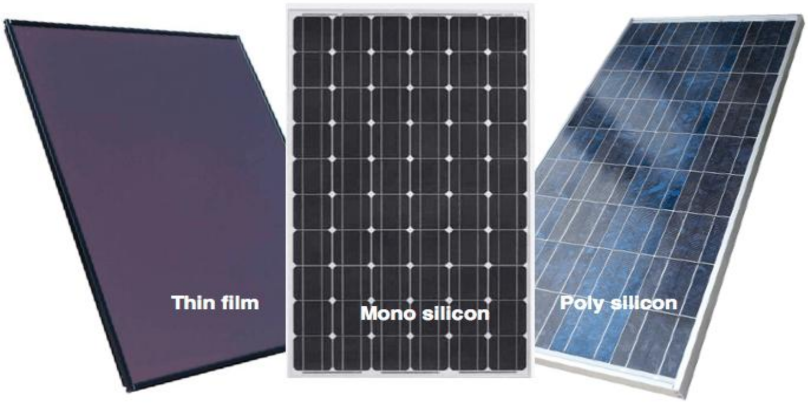

Figure6. Comparison of the promising technologies

5. SOME THIRD GENERATION SOLAR CELLS

H. Quantum Dot Solar Cells

QDSC holds the greatest next generation promise. From the past 10 years the latest advancement in epitaxy growth has been achieved to 63%. But due to slight photon absorption the performance greatly decreases. By enhancing QD optical absorption and its growth, light trapping techniques can be optimized. The material used to make quantum dots is lead sulfide PbS. The main leading principle is the variable dot size below the Exciton Bohr radius and the tunable band gaps and hence can be correlated as artificial atoms.

Fabrication process includes suspension in colloidal liquid where fumehood is required fig.7. Next, minimized groups are produced at a large level called as dots and can be spread by spin coating, spray on, and roll printing techniques which makes them cost effective. Stability is an important fabrication step imparted to nanoparticle solutions by long hydrocarbon ligands. For creating a solid mass these nanoparticle solutions are clarified and instead of long crosslinkers, short linkers are applied. By application of these chemicals the deteriorating steps of fabrication i.e. carrier recombination are curtailed leading to obvious enhanced efficiency of greater than 8% promising accessible infrared energy as in quantum dot solar cells in fig.8.

Plasmonic structures and metal nanoparticles e.g. nanostars offers new avenues for increasing optical absorption manifolds by quantum-dot-in-a-fence (DFENCE) structure comprising of InAs QDs and minimal $Al_xGa_{1-x}As$ "fence" layers (large band gap). According to recent studies the enhancement has reached approximated to 300. But surface nanoparticles together with metal nanoparticles improve optical path. QD optimization is achieved by boosting photocurrent and increase in short-circuit current density and open-circuit voltage is obtained by truncation of the height of dot [4]. This leads to enhanced photocarrier extraction and diminished carrier recombination. Different types of QDSC are: InAs/GaAs QDSC, colloidal QDSC etc.

Applications:

1. 1.QD Printing monitor and display
2. 2.Inkjet printing required for fabricating OLED using QD
3. 3.It improves LCD in terms of color gamut, color accuracy, and reducing power consumption

Advantages:

1. High efficiency in conversion of short wavelength to long wavelength i.e. from blue to green/red.
2. best light emitting material
3. being organic makes them really stable.
4. in the range of 25 nm at full-width half-maximum (FWHM it has spectral narrow emission.
5. tunable emission.

Disadvantages:

1. 1.bulky size and inability to diffuse across cellular membrane results to be toxic for cell if used in any biological application.
2. larger lifetime is an hindrance in some experiments and applications where quick biodegradation isrequired
3. 3.They may blink and become invisible leading to deterioration of quantum yield, meaning that the ratio of the emitted to the absorbed energy is rather low.
4. blue emitting QDs manufacturing is a difficult process having smaller sizes than the rest of the color emitting dots and an amplified emission so that which makes it detectable to human eye.

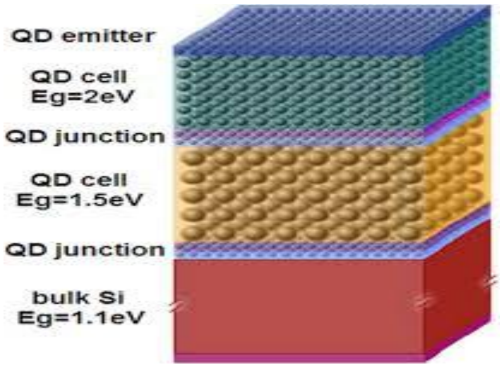

Figure7. Energy band structure of QDSC

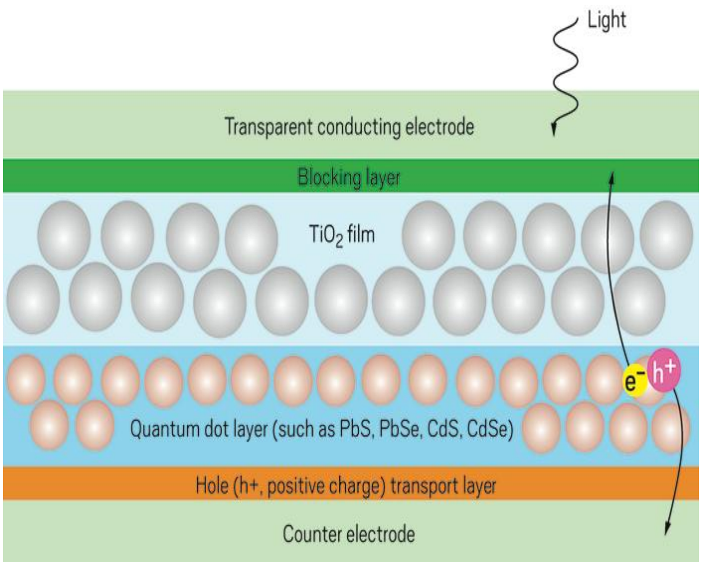

Figure8. Structure of quantum dots

I. DSSC(Dye-Sensitized Solar Cell)

A third generation solar cell invented in 1991 is responsible for artificial photosynthesis because of the reason they mimic absorption of natural light as it implies formation of photo electrochemical system through a semiconductor between a photo-sensitized anode and an electrolyte. It can produce electricity indoor and outdoor for artificial and natural light conversion. Fabricated by roll printing techniques as against glass based techniques these are semitransparent, semiflexible, colorful appearances, possible plasticity. With highest efficiency record has increased from 7% to 14% and has a good performance ratio. Element-free organic dye sensitizers are used for the preparation of photoanodes ,quasi/all-solid-state electrolytes, and metal element-free electrocatalytic films in DSSCs promises cell efficiencies of >5%. Some polymer act as binder, dispersant, and template to prepare the functional TiO2 films with light-scattering effect, suitable pore size, and surface area. Carbonaceous materials like CNTs and grapheme when combined with TiO2 films it results in boost of electrical conductivity.

DSSC consists of an electrolyte containing iodide/triiodide redox couple fig.9, a mesoporous photoanode alongwith dye-sensitized titanium dioxide (TiO2) film, , and a counter electrode with platinum (Pt) catalyst. A photo-excited electron upon absorption of light energy is injected from the excited state of the dye to pass into the conduction band of the TiO2. The electron passed through the TiO2 film by a driving chemical diffusion gradient and is collected on TiO2 film which is a transparent conductive layer of fluorinedoped tin oxide (FTO) glass substrate. Next, the electron is reintroduced into the DSSC and I3 - is reduced to I - which regenerates the oxidized dye (Dye+) so that dye cannot produce another chemical reactions [5]

For photoanode preparation some organic materials of polymers and carbonaceous are used for efficient production of mesoporous TiO2 nanocrystal films on the other hand photo-sensitive organic dyes can contribute to high solar-to-electricity conversion efficiencies. For preparation of electrolyte polymer gelators and ionic liquids were used for the long-term stability of the DSSCs to form solid-state or quasi-solid-state electrolyte. Preparation of counter electrode is based on organic materials of conducting polymers and carbon materials. Which facilitate low costs and future industrialization of DSSCs [6]. The efficiency can be increased by modifying the dye molecule leading to increased light absorption or modifying electrolyte and electrode structure to hinder internal resistance or increasing aperture ratio or using small dye molecules so that large no. of molecules can be binded in the semiconductor platfrorm fig.10.

Advantages:

1. thin layer of conductive plastic on the front side of DSSCs allow radiation of heat much easily & quickly making it operatable at low internal temperatures. Mechanical structure offers higher efficiencies in higher temperatures.
2. It performs dual function of producing electrons and electric field provider with silicon, as in a DSSC, where charge transport & the photo electrons are supplied by a different source(dye).
3. Efficiency around 11% is provided to rooftop solar collectors. as compared to thin-film technology cells ranging from 5% and 13%, and traditional silicon cells which operatable between 12% and 15%.
4. DSSCs can operate in low-light conditions i.e. under cloudy weather conditions and non-direct sunlight. The low cutoff in DSSC makes it useful for indoor usage, to collect energy for small devices from the lights in houses.

Disadvantages

1. DSCC is not manufactured in commercial scale yet for large-scale deployments.
2. Liquid electrolyte, is not very stable at varying temperatures since it can freeze at low temperatures cutting power production posing physical damage. Also when the liquid expands at higher temperatures sealing the panels becomes tedious.
3. The electrolyte solution contains volatile organic solvents requirirng carefully sealing but replacement through solid electrolyte is still to be explored.

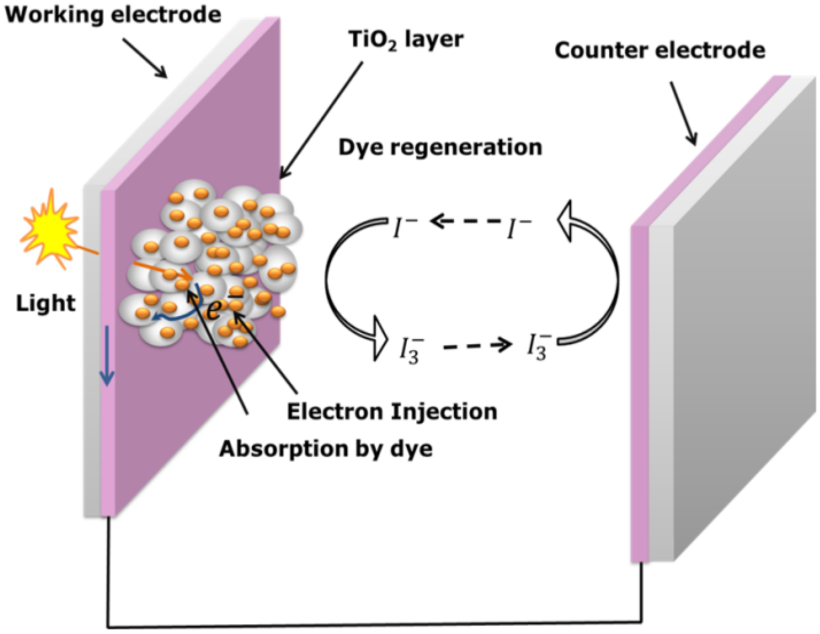

Figure9. DSSC device

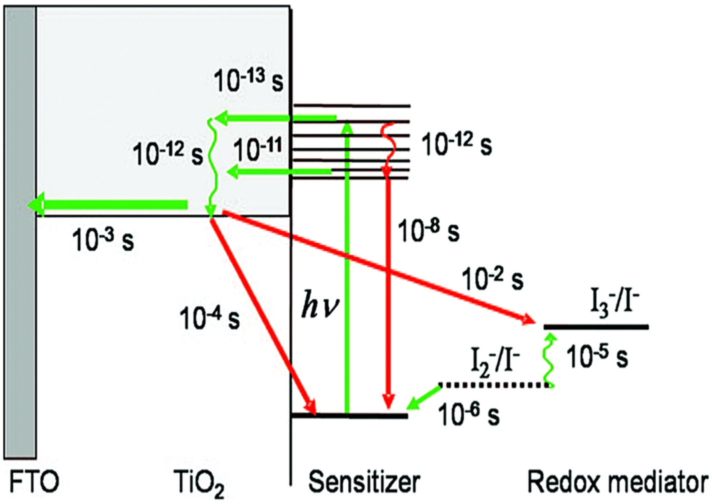

Figure10. DSSC operation

J. NANOCRYSTAL SOLAR CELL

On a silicon substrate**,** nanocrystals of silicon, CdTe or CIGS are formed through nanostructuring. In colloidal synthesis, spin coating results in thin film of nanocrystals where some amount of quantum dot solution is applied onto a flat substrate,and rotated fastly to distribute solution evenly. Until the required thickness is achieved the substrate is spun. Silicon nanocrystals also reveals multielectron effect with materials containing toxic elements such as lead or cadmium as compared to silicon which is both safe and abundant. Nanocrystals could theoretically convert more than 40 percent of the energy in light into electrical power by generating multiple electrons can be generated from high-energy photons. In the cell working semiconducting ink layer is exposed to lighy to breaks up the electrons. The top layer begins of the circuit anad conducts through the second layer of P/N junction,. Fourth layer behaves to be electrode made of molybdenum, and as the end of the circuit [7].

Colloidal inorganic nanostructures offer great potential by providing building blocks by tunable electronic properties, strong solar absorption and high carrier mobilities for efficiency enhancement. Also 3-dimensional nanocrystals and hyper branched nanocrystals promises potential for transport and percolation improvement in hybrid solar cells. Apart from practical benefits in device processing, they also inform about operation of hybrid solar cells, shedding light on key phenomena.

Advantages: Costs less to manufacture electricity, conventional solar panels and coal, maintenance and installation costs. Durablity and verstality, rapidness and Cheaper than conventional solar panel.

DISADVANTAGES

1. for interconnecting of the panels sliver metal is used making it expensive and sliver metal has the low resistance so it is limited to Rooftops, Cars, Laptops, Cell Phones, etc.
2. integration and stability proves difficult, requiring high processing costs and tolerance to defects and disorder

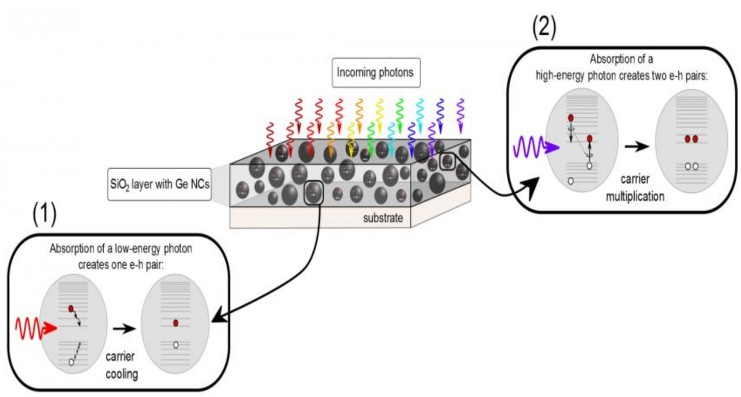

Figure11: Nanocrystal solar cell-device mechanism

6. SOME FOURTH GENERATION SOLAR CELLS

K. Hybrid solar cells

By definition it means organic semiconductor + inorganic semiconductor. Organic materials are polymers to absorb light as donor to transport holes whereas inorganic material are light acceptors to transport electron in structure. This combination aims at production of organic photovoltaics (OPV) and tunable absorption spectrum from inorganic compounds. Current compounds used are cadmium sulfide promising efficiency of 4%, silicon, metaloxide nanoparticles alongwith less band gap nonaoparticles. The assembling of photon absorber and exciton donor results in a heterojunction photoactive layer which has greater efficiency than single material. Charge transfer takes place and exciton is delocalized through the energy provided by conduction bands of donor and acceptor.

After delocalization carriers travel to respective electrode via a perlocation network along the exciton diffusion length. The generated excitons close to acceptor i.e. inorganic material produce photoelectric current. When these particles move throughout the polymer a large area is provided for charge transfer and photocurrent [8].

Advantages:

1. Renewable energy is best utilised and since environment is unstable, so the system is synchronized with energy generating minimal period design to handle worst-case scenario. On other hand system's capacity is too large for other times. generated by solar radiation peak periods where wastage should be avoided.

2 . for large systems because of change and instability leads to larger supply which can not meet the load demand of the system, so using a renewable source of hybrid system will greatly dimishes the load probability.
3. as differentiated with single-use diesel solar generator systems, less maintenance and less use of fuel is required. Hence fuel efficiency increases.
4. Better load matchingis achieved because the diesel generator provides greater power, the hybrid system is applicalble to a wider range of load system, e.g. large AC load, impact load and so on.
Disadvantages

1. Control and monitoring becomes more complicated due to variety of energy sources, e.g. the process of synchronisation of various energy sub-system, coordination of system thus leading to complexity of control system
2. Complex Large initial project and Hybrid system design alongwith installation, construction engineering projects, maintenance of oil machines
3. The PV system is noisefree and pollution free but due to hybrid diesel engine noise and pollution cannot be avoided.

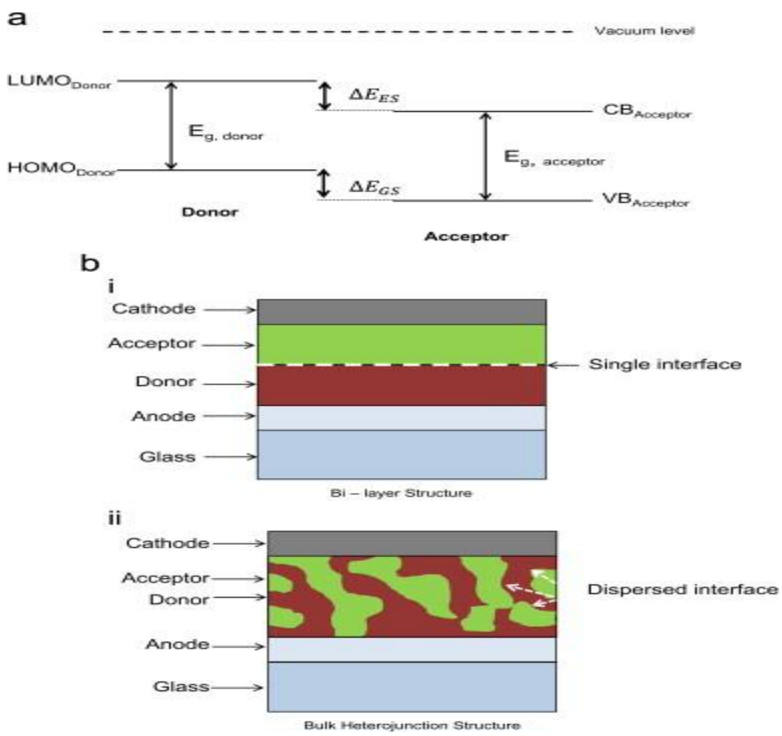

Figure12: Energy band diagram of hybrid solar cells

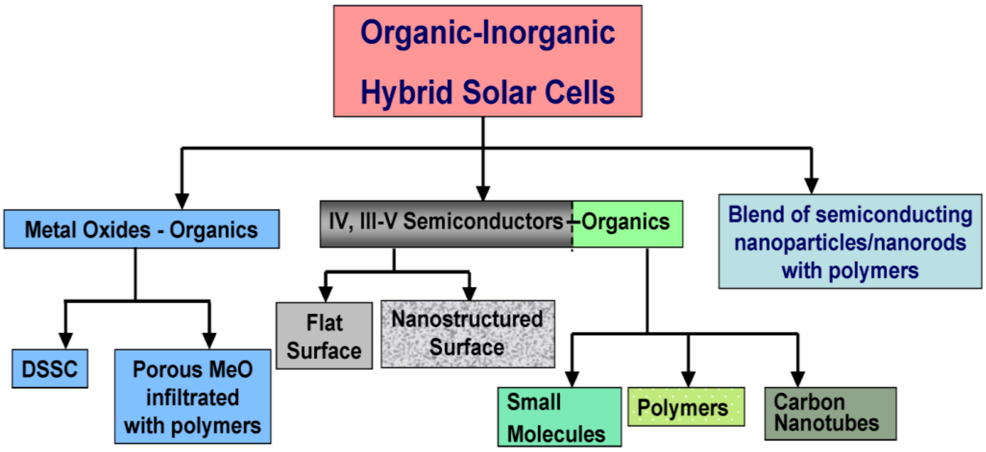

Figure13: Classification of hybrid cells

L. Perovskite Solar Cell (PSS)

Perovskite SC is naturally occurring with certain minerals making it a prevailing technology and is a hybrid organic-inorganic material in solar cell research as compared to Dye-sensitized solar (DSS) cells, and others which are comparable to crystalline Si solar cells because of low-temperature solution technique. PSS have reported intensified output of 21% from approx 9.7% after emerging in 2012, but less account has been gateherd for their low stability. Also Halide perovskites has shown signs of future success for delivery of the next generation of solar cells as in fig14. These enhance power conversion efficiency when distinguished with silicon and cadmium telluride, amorphous, CIGS. The constant growth in stability is soon going to touch the market requirements but the toxicity of lead, a constituent responsible for better performance of PSS. When we consider tin-based ABX3 perovskites, they are being extensively explored Offering the optimum band gap for the highest power conversion efficiency leaving behind lead-based analog [9]. The different approaches gathered include:

- assurance of water and oxygen-free conditions during device life span.
- deteriorating atmosphere during device preparation
- style of Chemical doping in perovskite
- Morphological control reduce the detrimental
- effect arising due to grain boundaries.
- making perovskite surface to be unreactive
- New perovskite formulations composed of halides and cations

It is derived from the ABX3 crystal structure as shown in fig. of the absorber materials like firstly methyl ammonium lead trihalide (CH3NH3PbX3, wherein X represents halogen ion (I−, Br−, Cl−), and band gap which is dependent on halide content ranging from 2.3 eV and 1.6 eV and secondly Formamidinum lead trihalide (H2NCHNH2PbX3) having bandgaps 2.2 eV and 1.5 eV as shown in fig15.

The fabrication and processing is less complex over traditional cells previously reported as they require high temperatures and vacuums responsible for high silicon purity which can be depicted in the fig. now PSC which is organic and inorganic (a strength) can be manufactured with wet chemistry and simple lab environment by methylammonium and formamidinium lead trihalides manufactured by various solvents where they are spun on a substrate and vapour deposition techniques. Now the solvent technique has strong ionic interaction at low temperature due to organic compound and hence evaporation and selfassembly is done dense layers of PVS. Due to non-homogeneity additional typical chemicals are required such as GBL, DMSO, and toluene drips because simple solution hinders efficiency [10].

Second technique is based on solvent-solvent (NMP is used-N methylpyrrolidone: ann organic solvent) interaction for high quality crystalline films with thickness ranging from 20nms –large cms. This solvent is coated on substrate where substrate is bathed in diethyl ether (DEE) which grabs NMP. This proves to be the best technique in fig.16.

Vapour deposition technique, temperature of 150 °C is required for exfoliated lead halide is annealed with methylammoniumiodide vapor useful for mutistacked thin films and multi junction cell. Both techniques are promising options in scalability for mesoscopic designs like coatings on a metal oxide scaffold, DSSC etc. After these techniques no extra solvent are required but what remains a problem is issue of degradation of standard environmental factors. The synthesis process in fig. 17 can be understood [11].

Advantages :

1. Atremendous rise in the efficiency of the mineral has been reported i.e. from 3% to 20%. Which reveals that over a couple of years PSC managed to achieve power conversion efficiency much larger than photovoltaics.
2. As compared to silicon perovskite is less expensive to produce. Researchers believe that the mineral will lead to production of solar panels costing about 10 to 20 cents per watt.
3. Perovskite on one side being a great light absorbent it also emits light requiring less material compared to silicon to absorb same amount of light .
4. It has a direct optical band gap of 1.5eV with les carrier recapturing leading to long minority carrier lifetime
5. Liquid perovskite can be sprayed on a substrate material so that manufacturing is done in high amount with low cost

Disadvantages:

1. Perovskite breaks down quickly on exposure to environmental factors like few dros of water heat, snow, moisture etc. making survival for decades questionable.
2. Though the toxin level has gone down in recent years, the mineral is still toxic because of methyl ammonium lead iodide.

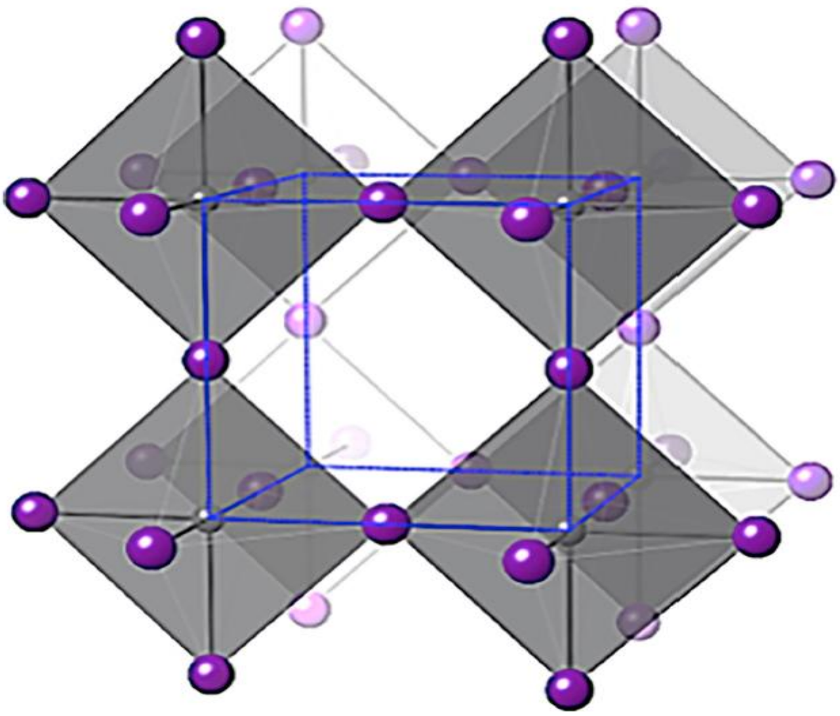

Figure14: ABX3 perovskite crystal

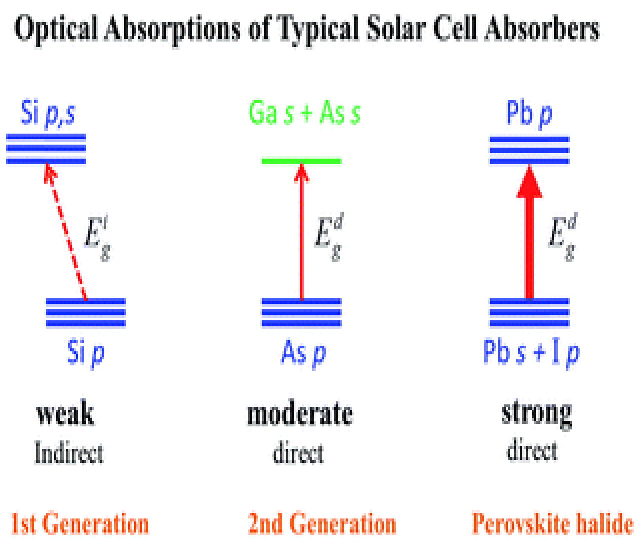

Figure15: Band gap description for PSS

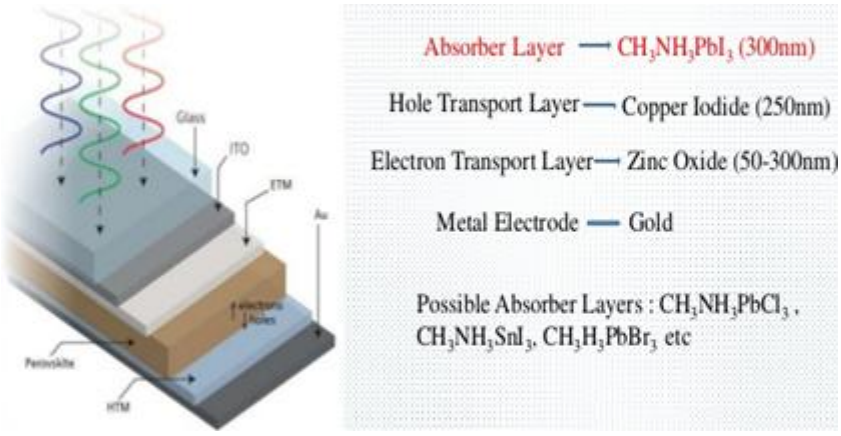

Figure16: Basic working of PSC

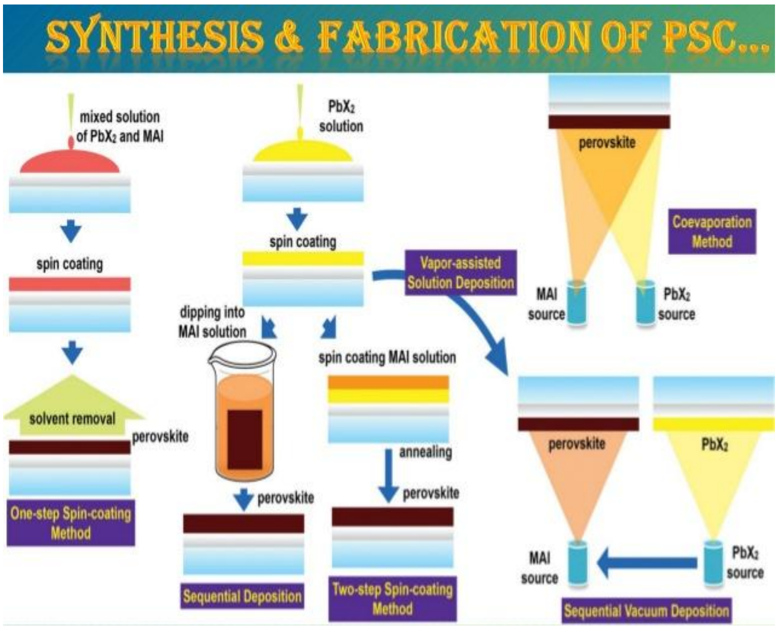

Figure17: Fabrication process

CONCLUSION

The review discusses latest first, second, third and fourth generations solar cells but focuses on some materials like nanocrystal, perovskite etc.With the new discovery of carbon nanotube structure.Which has the capacity of transporting electrical charges 100 million times they can be implemented for absorption enhancement of light. However, arrangement of randomly ordered nanotubes still pose a problem. So in this review it has been revealed that perovskite mineral has the potential for solar conversion to current less costly than ever before. Thickness of billionths of a meter, in perovskite cells offer 40 percent cheaper rates and efficiency to be 50 percent more than those commercially produced today. Regardless of sun's direction perovskite can absorb most of the solar spectrum and work in various atmospheric conditions. As compared to silicon or thinfilm based technologies which are are processed using vacuum-based techniques and are expensive. Perovskite panels is are still under test material so that more properties can be discovered, before companies embark on industrial-scale production. The photovoltaic (PV) energy market has been drastically improving and growing and the International Energy Agency has said that solar energy could be the world's biggest source of electricity by 2050.

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