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A SURVEY OF SOLAR CELL MATERIALS

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Abstract **-Now a days a lot of research is going on Solar cells with an intention to discover a suitable material to fabricate a solar cell of better performance. To fabricate solar cells different technologies are developed at different stages. As materials play vital role in the fabrication of solar cells, a literature survey is made on solar cell materials and the paper is intended to through light on solar cell materials used in the fabrication of solar cells. Recent progress in the values of important parameters of different solar cells is summarized. The paper is concluded with a scope of research in future.**

Key words **- Solar cell, power conversion efficiency, Dye sensitized solar cell, quantum dot solar cell, organic solar cell, perovskite solar cell, tandem solar cell**

1.INTRODUCTION

The conventional energy sources are given by Coal, Oil, Natural gas, Nuclear power, Wood, Straw, Cow Dung .These are also known as non - renewable energy sources. The renewable energy sources are given by Wind Energy, Bio Energy, Tidal Energy, Geothermal Energy, Solar energy. The conventional energy sources (oil, gas and coal) are available in a fixed quantity and cause environmental pollution. As per an estimation coal, oil, natural gas can last only for a few decades. So non-conventional energy sources gained importance. Among these sources Solar Energy Systems require no maintenance and will last for decades. Once installed there are no recurring costs. They work without causing sound pollution and generate electricity or heat at home. In fabricating solar cells suitable materials of specific properties are used.

So it becomes necessary to understand the different materials used to fabricate solar cells.

2.SOLAR CELL AND ITS PARAMETERS

Solar cell is a photovoltaic device(p-n junction) i.e., a device that generates voltage when exposed to light. Infact eletron-hole pairs(or excitons) are generated in a solar cell when it absorbs light[1]. The generated carriers are seperated by an internal field and extracted into external circuit which results into current and volage drop across load. The volt-ampere characteristic curve (Fig.1) and equivalent circuit(Fig.2) of a solar cell are given below.

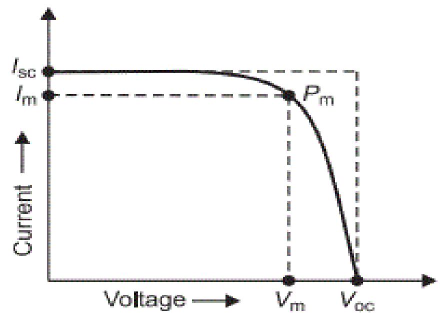

Fig.1.V-I Characteristic curve

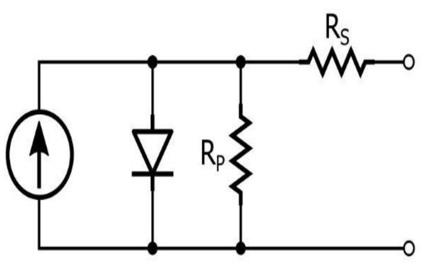

Fig.2. Equivalent circuit

The basic parameters of a solar cell are given below[2].

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2.1. Open circuit, V_{OC}

The open-circuit voltage (Voc), is the maximum voltage available from a solar cell, when its terminals are left open while current becomes zero.

2.2. Short circuit current, I_{sc}

The short-circuit current (I_{SC}) is the maximum current produced when terminals of solar cell are shorted while voltage becomes zero.

2.3 .Fill factor,FF

Fill factor is the parameter that gives the ratio of maximum power obtained to maximum theoretical power.

$$Fill\ Factor,\ \mathrm{FF} = \frac{V_m I_m}{V_{oc} I_{sc}} \qquad (1)$$

2.4. Power conversion efficiency, PCE

Power conversion efficiency is defined as the ratio of the output power to input power.

$$\eta = \frac{V_m I_m}{P_{in}} = \frac{V_{oc} I_{sc} . FF}{P_{in}} \qquad (2)$$

An ideal solar cell will have fill factor of nearly unity and very high power conversion efficiency.

3. RECENT TRENDS IN SOLAR CELL MATERIALS

Different solar cell materials are discovered at different stages to fabricate solar cells[3].

3.1. Single crystalline silicon solar cell: The first solar cell fabricated is a single crystalline silicon solar cell which is developed in 1953, mainly, to use in space crafts. This is referred as first generation solar cell. It is fabricated using pure silicon obtained from sand. Silicon has a band gap of 1.1eV and absorbs maximum amount of visible region solar spectrum. So this solar cell is found to have high efficiency of about 20%,high stability but it is costly because of fabrication at elevated temperatures. Diffusion of phosphorous is the most common practice to form the emitter for p-type crystalline silicon (c-Si) based solar cells. It is discovered that the SiP precipitates are usually formed in the emitter of c-Si during diffusion of phosphorous and they become the recombination centres for the minority carriers and hence the performance of c-Si solar cells degrades[4]. The SiP precipitates in the emitter region can be effectively eliminated by using a post anneal treatment. As a result, the solar cell exhibits a higher conversion efficiency than the conventional one by a value of 0.2%

3.1.1.Poly crystalline silicon solar cell:

The development of $ZnAl_2O_4$(gahnite) spinel nanostructure through anti-reflection coating (ARC) instead of TCO improved power conversion efficiency (PCE) of polycrystalline silicon solar cell to 21.27% at open atmospheric condition and 23.83% at controlled atmospheric condition. Thus the gahnite nano-microfilm is an appropriate ARC material for polycrystalline silicon solar cells to enhance the PCE. The optical band gap values of gahnite-coated solar cells are obtained as 3.7, 3.65, 3.52, 3.28 and 3.10 eV for Gahnite nanosheet coating on the silicon solar substrate performed at different time periods of 5 , 15 , 25 , 35 and 45 minutes of coating, respectively[5].

3.1.2 Amorphous silicon solar cell with interface layers

The results reveal that the stability of the solar cell with buffer layer at p/i interface has significantly improved. It is found that the solar cell with p/i buffer layer has only 13.42% degradation in power conversion efficiency after 1000 h light soaking and the cell without any interface treatment, the degradation in efficiency has reached 23.56%[6].

3.2. Thin film solar cells :In order to reduce the cost of solar cells, thin film solar cell technologies are developed. These are referred to as second generation solar cells.

3.2.1.Amorphous silicon solar cell:

Thin film amorphous silicon based solar cell has received much attention due to its several advantages. However, light induced degradation(LID) is the major problem of the amorphous silicon solar cell. For this reason, hydrogenated micro crystalline silicon solar cell (μc-Si:H) has got considerable significance as it has negligible amount of LID. A sample of this material has efficiency of 7.75% . The effect of the n-µc-SiOx:H materials on the solar cell performance was evaluated by incorporating these layers as n-layer in single junction µc-Si solar cells.The different samples are found to have refractive indices ranging from 2.4 to1.98. Sample cell 35 containing with bi-layer of n-layer NMO-28 and NMO-29 together has improved efficiency of 8.44%[7].

3.2.2 Cobalt doped PbS thin film solar cell:
The power conversion efficiency of PbS thin film is found to be increased from 2.02 to 2.49 by doping with Co from 0% to 5%. with sample energy gaps ranging from 1.89 to 2.02eV[8].

3.2.3 : CZTS thin film solar cells:
Copper Indium Gallium Selenide(CIGS) and CdTe thin film solar cells have remarkable efficiency but found to have some environmental issues. The elements like tellurium (Te), indium (In) and gallium (Ga) are expensive and toxic in nature. Synthesis of non-toxic kesterite Cu_2ZnSnS_4 (CZTS) nanoflakes thin film by facile, one-step and inexpensive chemical bath deposition method without any post deposition treatment and ZnS as a window layer were fabricated on FTO coated glass substrate with 'Glass Substrate/FTO/ZnS/CZTS/Ag' device configuration which resulted in 1.71% efficiency and higher absorption with a band gap value of ~ 1.6 eV[9].

3.3. Third generation solar cells

The discovery of new materials made it possible to fabricate variety of solar cells using technologies viz., DSSC technology, organic solar cell technology, nano particle solar cell technology, perovskite solar cell technology etc., which are known as third generation technologies.

3.3.1 Dye sensitised solar cell(DSSC):
Its operation is similar to that of a photosynthesis process. The dye of DSSC absorbs light, generates carriers, transport carriers to the external load at higher voltage and brings back the carriers in the cell at lower voltage.

Organic dyes that can be used in solar cells have many advantages. These dyes contain a greater number of adsorption layers than the metal compositions and absorbs a wider range of spectrum. The cost of organic dyes is also low. Zn(II) metal Schiff-base complex with ligand is found to higher efficiency of 0.73. So Zn(II) metal Schiff-base complex synthesized at low cost, would be a potential sensitizer for dye sensitized solar cell devices[10].

3.3.2 Organic solar cells
It contains an active layer(Dye in case of DSSC) obtained from conjugate polymer and small molecule organic polymer material known as donor material and acceptor material(equivalent to n and p regions of inorganic semiconductor). Here the absorbed photon generates bounded electron -hole pair known as exciton. To make the carriers free, hole transporting layer (PDOT:PSS) and electron transporting layer(Ca)are used on either side of the active layer. Commercial organic solar cell uses the combination of P3HT (Donor) and PCBM (acceptor) to get efficiency of about 5%. It has been reported on the effects of air action on the physical entities related to the transport processes in organic solar cells. It is found that the ITO/PEDOT:PSS/PTB_7-Th:PC_{71}BM/Ca/Al device has variations in series and the shunt resistances with the air exposure time and hence conversion efficiency is get effected. The experimental values of *FF* for zero exposure time and after 43 h of exposure to air are found to be 0.76 and 0.65, respectively[11].

3.3.3. Organic small molecule solar cells

The promising materials for the fabrication of small molecule solar cells are Copper phthalocyanine (CuPc) and zinc phthalocyanine (ZnPc). The low solubility of CuPc and ZnPc causes a bad morphology of CuPc (ZnPc)/C60 films which results into unsatisfactory power conversion efficieny. However continuous CuPc(ZnPc)/C60 composite films are obtained by stripping-transfer method[12]. The performance of the small-molecule solar cells prepared by stripping-transfer method was better than devices prepared by the traditional evaporation method with a device structure of ITO/CuPc (ZnPc)/C60/Carbon paste. Due to the strong optical absorption of ZnPc, the efficiency of small-molecule solar cells using ZnPc is higher than devices using CuPc, and the efficiency could reach 1.37%. Thus composite films formed by this low cost and convenient method, makes it suitable for commercialized solar cells.

3.3.4 Organic solar cell based on conjugated polymers/fullerin blends

Organic solar cells have been reported to be promising alternative to the inorganic solar cells. The performance of organic solar cell (OSC) has continuously improved with power conversion efficiencies (PCE) approaching 9 % for cells based on conjugated polymer/ fullerene blends , 9.5 % with inverted structure and over 12 % for tandem architectures in small area devices .It was found that the blend ratio and donor–acceptor concentration of PCDTBT:$PC_{71}BM$ significantly affects the solar cell performance. The highest value of PCE is obtained at the blend ratio of 1:4 is of 2.25 %[13] .

3.3.5. Nano particle solar cells:

The simple domestic microwave oven has been used successfully to synthesize spherical nanoparticles of zinc oxide (ZnO NPs) for solar cell fabrication using Azadirachta indica (Neem) leaves extract[14]. The average nano particle size is found to be around 4.2 nm. The maximum absorption wavelength for the synthesized ZnO nanoparticles was found to be higher than 352 nm. The cell efficiency of the prepared sample is 2.1% which is higher than that is achieved with previous studies on nanoparticles.

3.3.6. Perovskite solar cell

The chemical composition of perovskite crystal is given by the formula AMX_3 where X is halide anion such as O, Cl, Br and I while M refers to a metal cation with a coordination number of 6 and A is usually a large cation that fills the cuboctahedral holes with coordination number of 12. Here A cations can be organic or inorganic like Methyl Ammonium (MA), Cs. To absorb photons of longer wave length the band gap tuning is performed by changing in any of A, M and X in AMX_3 . $CH_3NH_3PbI_3$ is the most commonly used material for making high efficiency perovskite solar cells and has a direct band gap of 1.55 eV with absorption coefficient as high as 10^4 – 10^5 cm^{-1}. It is reported that for a MAPbI3 perovskite using inorganic hole transport material such as CuSCN and of structure FTO/TiO_2/MAPb I_3/CuSCN/Au has a PCE of 9.2% which is higher that of hole transporting material CuI[15].

3.3.7 Layered perovskite Solar cell

The layered perovskite $Sr_{1-x}Sn_xB_{1.95}La_{0.05}Nb_2O_9$ (x = 0.0, 0.01, 0.03, 0.05, 0.1 and 0.2) SSBLN was investigated in a new-doped form for hole as well as electron transport layer (HTL/ETL) in perovskite solar cells[16]. The energy gap of material ranging from 2.8119 to 2.5519 for different tin concentrations. Decrease of optical energy band gap provides motivation of further study for perovskite photovoltaic applications using current SSBLN compositions.

3.3.8. Multi junction Tandem perovskite solar cell:

Tandem cells are effectively a stack of different solar cells on top of each other. By arranging them like this, we can capture more energy from the sun. The discovery of the first double perovskite took place is the late 1950s. Recently it is discovered that the polycrystalline compound of $Pb_{1.5}Ca_{0.5}BiNbO_6$ has a double perovskite structure[17]. Different characterization methods reveal that the material has a higher value of room-temperature dielectric constant, remnant polarization and useful for energy storage devices.

RESULTS

The experimental results obtained from the various investigations are shown in Table I for the sake of comparison. They are obtained under specific experimental conditions. But they show recent progress in solar cell parameters.

Table I. Parameters of different solar cell materials

Material	V_{OC} (V)	J_{SC} (mA/ cm^2)	FF (%)	η (%)
p-type crystalline silicon (c-Si) modified profile	0.6388	8.731	80.3 9	18. 74
$ZnAl_2O$ spinel nanostructure through anti-reflection coating of polycrystalline silicon(T-IV)	0.664	42.115	79	21. 27
Micro crystalline silicon solar cell (μc-Si:H) with bilayer (cell No.35).	0.48	25.73	68.3	8.44
Co-doped PbS (doped with 5% of Co)	0.40	11.39	55	2.49
Cu_2ZnSnS_4 (CZTS) nanoflakes thinfilm	0.5838	5	59	1.71
Zn(II) metal Schiff-base complex with ligand	0.60	2.71	-	0.73
Small molecule ZnPc/C60 composite film obtained by all solution stripping transfer method	0.51	4.29	53	1.37
PCDTBT: $PC_{71}BM$ solar cells with blend Ratio 1:4 at concentration of 12 mg/ml	0.68	9.26	35. 77	2.25
Sphercal Zinc oxide (ZnO NPs) nano particles obtained using Azadirachta indica (Neem) leaves extract.	0.73	4.5	63	2.1
Perovskite of structure FTO/TiO_2/MA PbI_3/CuSCN/ Au	0.89	16.82	61.4	9.20

CONCLUSIONS

India's solar installed capacity reached 26 GW as of 30 September 2018. More than 90% of the present market share is taken by silicon PV solar cells because it delivers a package of decent module efficiency of 21% with lifetime of more than 25 years and cost of 0.3 $ W−1. In contrast Solar cells fabricated using organic, perovskite materials are relatively cheaper but unstable to atmospheric conditions and have smaller life time. By optimizing morphologies, high performing OPVs with PCEs above 15% can be obtained in the near future for their commercialization to advance the OPV market.

After only few years of work, perovskite solar cells of efficiency 15.9% with facile low temperature solution-based fabrication method, high absorption coefficient, higher stability in air, very high values of open circuit voltages, high diffusion length, high charge-carrier mobility's are discovered. Hence, it is an optimistic expectation that the PCE of single-crystal perovskite solar cells would increase to 25–30% soon[18].

SCOPE OF RESEARCH

Research is required into the fabrication of long-lasting OPVs that can resist morphological degradation under diverse environmental conditions. Despite the rapid progress in the performance of hybrid perovskite solar cells, there are still many more opportunities for further improvement. The interaction mechanism between the hybrid perovskite and other interface layers still remains unclear and needs to be further explored to facilitate the application of morphology engineering. In addition to experimental approaches, theoretical calculations can definitely make a significant contribution to further advances in the design of morphological techniques. Knowing the basic properties of a semiconductor material, such as carrier concentration, trap position and density, carrier mobility, carrier lifetime, diffusion length is a primary step before designing a suitable application for it. This also holds true for perovskite materials. A more research is needed in the Perovskite/silicon tandems to have higher efficiency, long life time and at low cost.

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