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Components, Working, Fabrication & Characterization of Dye Sensitized and Perovskite Solar Cell

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Abstract—*Solar cell is one of the renewable energy technologies which can generate usable electricity directly. Solar cells, like other technologies, are classified into generations. The latest being the innovative third generation. In the third generation, DSSC and perovskite cell are the two very popular innovative researched cells. Use of Nano technology enhances the capacity. In the present work, the different parts of both the cells have been explained with 3D figures along with their working and flowchart of construction. Also both the cells have been fabricated. The DSSC (FTO/TiO_2/N719/KI-I_2/Pt) gave a VOC=0.591V & ISC=5mA and the perovskite cell (FTO/TiO_2/$CH_3NH_3PbI_3$/CuSCN/C) gave a VOC=0.486V & ISC=2.899mA. The reasons for their deviated performance are mentioned. Future prospects of these new advanced cells are also discussed in this paper.*

1. INTRODUCTION

Solar cells can harness sunlight to usable electricity. It comes next only to fuel cells in terms of number of research paper published. Solar cells are classified according to generations. The third generation solar cell uses innovative technologies to decrease the cost and improve efficiency. Of the new cells, the DSSC and its successor perovskite cell are two of the cells which have bright future.

DSSC are new kind of solar cell and it was invented by Gratzel. These cells could achieve efficiency of more than 7%. [1] For its fabrication, very high temperature, vacuum, high purified materials, costly and advanced equipment are not required. Therefore the cost can be just 25% of the conventional solar cell. DSSC can be flexible, transparent or of desired color.

On the other hand, perovskite cell requires high end technologies for fabrication and are extremely prone to humidity and environment and therefore have to be encapsulated. [2] These cells have achieved better efficiencies, compared to its predecessor DSSC but are relatively costly. [3]

Using nanoparticles the efficiencies of these cells can be enhanced. [4] Nanoparticles are particles having size in the range of 1-100 nanometers. The upper limit differentiates bulk matter from particles. These nanoparticles show enhanced electronic, photo-catalytic and charge transfer property. Also the energy band gap becomes a function of size of particles.

In this paper, the popular method to prepare the DSSC and perovskite cell has been explained in detail with schematic diagrams showing the essential parts of both. The assembling steps have also been explained. Simplified version of both the cells have been fabricated. The efficiency and cell characteristics have been mentioned. The problems associated with the cells and their deviated efficiencies in this experiment have been discussed. This also gives a glimpse of future aspects of these cells.

2. COMPONENTS, FABRICATION STEPS AND WORKING OF CELL

A In this section the 3D schematic diagram of the components, their fabrication steps and working principle for both DSSC and perovskite is explained.

2.1 Components of the Cell

Both the cells share the photo anode and the transparent conducting substrate. The other parts as explained in the schematic diagram are different for both cells. The different parts are discussed here. [5,6]

2.1.1 Photo Anode for the cell. In perovskite cells, the perovskite layer is coated over this layer and in DSSC dye is absorbed over this layer. Photo anode absorb dye molecules and allow the photoelectron to be conducted. Large surface area is preferred so that numbers of dye molecules are absorbed. Research is going strong to develop these photo anodes with Nano tubes/ Arrays, wire. [7-9] For photo anodes, other materials apart from TiO_2 are also been studied, specially ZnO and SnO_2 which have higher band gap.

Different methods are used to prepare this layer like sputtering, screen printing, spin coating apart from the conventional doctor's blade method. [10]

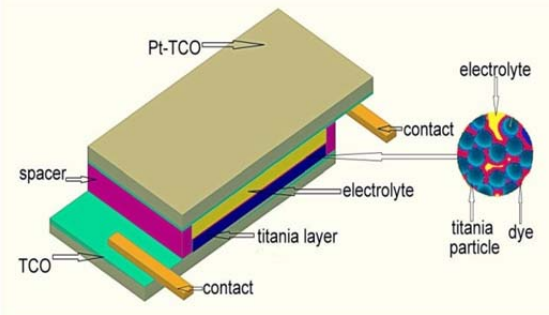

Fig. 1: Schematic diagram of DSSC showing the different components.

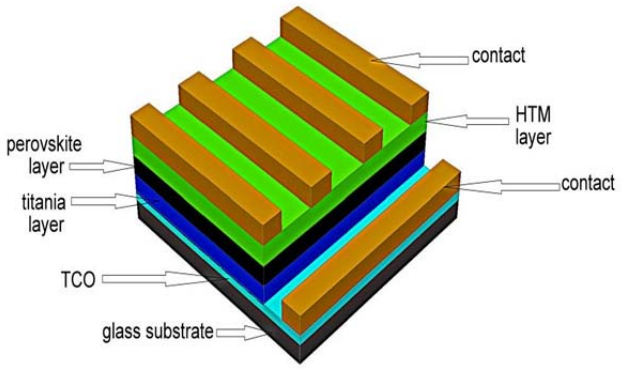

Fig. 2. Schematic diagram of perovskite cell showing the different components.

2.1.2 Transparent Conducting Substrate for the cell. Generally used TCOs are FTO and ITO. Their function is to collect current and support the n-type layer. They also act as catalyst for faster charge transfer. They should be transparent optically so that the sunlight reaches optimally.

Heating at 450 ˚C should be done to improve dielectric contact. For ITO film exposed to temp above 300 ˚C, the resistance increases leading to low efficiency. This happens due to reduction in carrier density. But FTO don't suffer from this problem. Although FTO has about 10% less transmittance than ITO, the resistance is lower and the price is reduced to $1/3^{rd}$ favoring it. [1]

2.1.3 Dye for DSSC. It absorbs the light and has the ability to affect the efficiency of the solar cell. For higher photo electric current, the dye should be having wide absorption spectrum. It should mate properly with the photo anode so that electron injected gives higher quantum efficiency. It should be stable toward irradiation.

The best dye which has these both properties are ruthenium based complexes. N719 dye is the most widely used Ruthenium dye when photo anode is TiO_2. [5] These dye increases the absorption capability of cell in visible range.

If organic dyes are used, they are cheap and efficient but not have efficiency of conversion as Ruthenium dye. N719 dye is modification of N3 foundation dye. [1] It has the ability to increase cell voltage. This is also referred as industry's "workhorse dye" as it is most widely used dye which gives high performance. It is more soluble than N3 foundation dye in polar solvent.

2.1.4 Electrolyte for DSSC. Generally liquid electrolyte is used but research work is going strong for solid state electrolytes. It has the function to conduct holes and reduce the oxidized dye. Liquid electrolyte used has higher efficiency but it comes at a cost. The sealing techniques are complex to stop the electrolyte evaporation. It also has tendency to leak and react with sealing materials and the tendency to de stabilize the dye. To overcome this, solid electrolytes are now being made and researched upon. The most commonly used liquid electrolyte been the Iodine based. [5]

2.1.5 HTM for Perovskite. For a perovskite cell, liquid electrolyte create problem as the carbon of the perovskite has the tendency to get dissolved in these electrolytes. P-type semiconductor like CuSCN and CuI were developed for this purpose. [1] Initially made cells with these were having efficiencies less than 1%.

The lower efficiencies can be explained due to unfilled voids between the crystal during deposition. For higher efficiencies spiro-MeO-TAD serves as one of the best hole transport material but is costly. [6]

2.1.6 Perovskite. Perovskite mineral was founded by Perovski, who founded Russian Geographical Society. Compounds having structure similar to that mineral came to be known as perovskite. Original perovskite is $CaTiO_3$.

Perovskite have the crystal structure of the form ABX_3. Where A can be large cation (atomic or molecular) placed at the center of the cube, B a cation (transition metal) which is placed at the corner of the cube and X a small anion placed at the face of the cube. [11]

Perovskite attracted attention due to good light absorption capacity, higher band gap of 1.5 eV, easy processing techniques and ability to get deposited from solution. [3] The $CH_3NH_3PbX_3$ types are the most popular ones.

2.2 Fabrication Steps of DSSC and perovskite cells (Commonly used Architecture)

The flow diagram to fabricate the popular architecture of both the cells is given here.

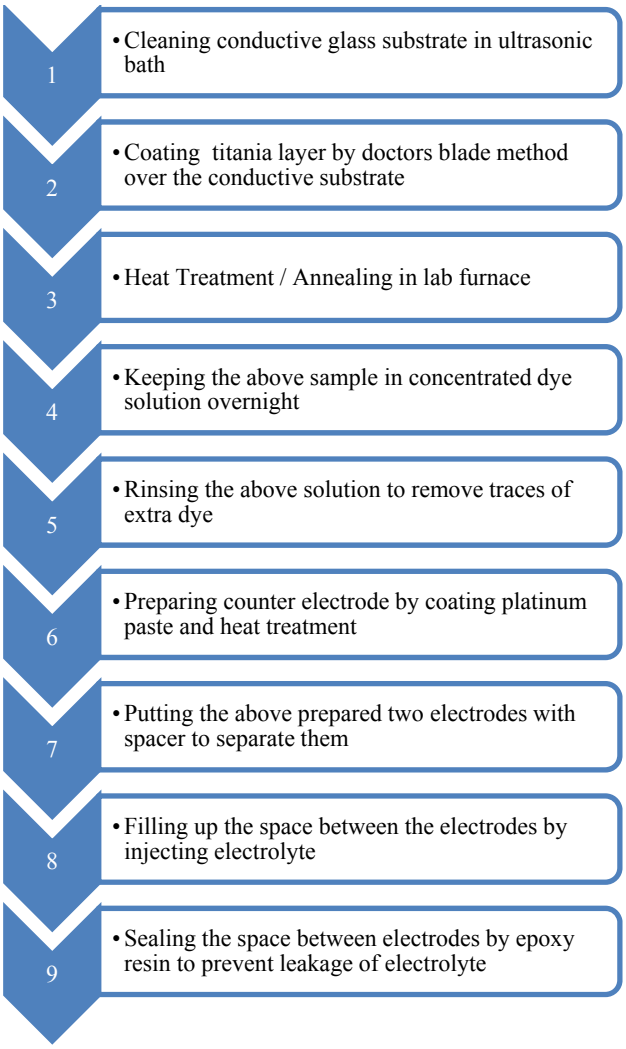

Fig. 3. Steps for fabrication of popular DSSC.

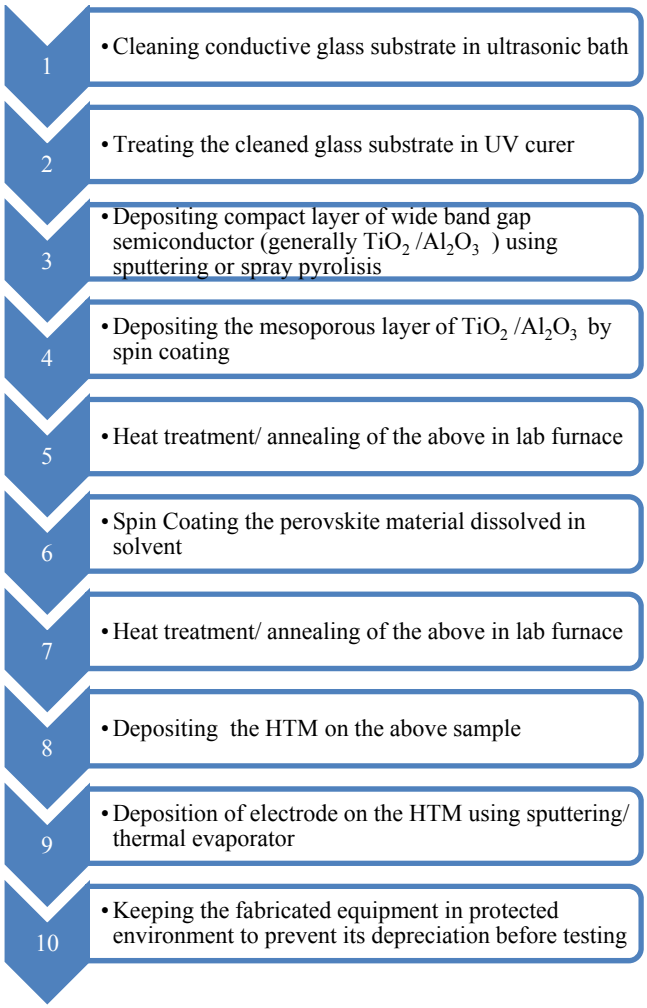

Fig. 4. Steps for fabrication of popular perovskite solar cell.

2.3 Working Principle of the Cell

This section deals with the working principle of both these cells.

2.3.1 Working of DSSC. Working of DSSC is similar to photosynthesis. Effectiveness depends upon the speed of reaction taking place. The most common dyes used are the ruthenium based. Ruthenium dye is used because of better bonding with TiO_2 and increased stability. Light is absorbed by a single molecular layer of dye, which is chemiabsorbed on a thin film of TiO_2. This promotes the electron of Ru^{2+} to go to an excited state. In pico to femto second, the excited electron get transferred into Conduction band of TiO_2. The charge gets separated effectively. The Ru^{3+} is formed by electron loss and titania gets negatively charged. Within nano seconds the Ru^{3+} are reduced by I^- of the electrolyte. The injected electron in titania diffuses to reach the conductive side. Electric charge extracted from photoande can be used to get power. To close the circuit, negative charges are directed to counter electrode where electrolytes get reduced. [1,12]

2.3.2 Working of Perovskite Cell General working principle of $CH_3NH_3PbX_3$ perovskite solar cell was explained by Pedro et al. using diffusion length. [13] Although derived from the DSSC, they are unique as they can work on both the sides (p as well as n type). Also the wide band semiconductor like titania is not required sometimes for functioning of cell. They also have better light absorption ability and better efficiency compared to its competitor. [3] Initial research has suggested that they may not work as conventional cells. Studies are going to find out the exact working mechanism of the cell so that they can be tailor made to meet the requirement.

3. EXPERIMENTAL SECTION

3.1 List of Chemicals

All the chemicals used for the experiments were standard analytical reagents.

TiO_2 powder, anhydrous ethanol, FTO glass, N719 dye, platinum paste, Iodine based electrolyte(0.5M KI+0.05M I_2), titanium isopropoxide, hydrochloric acid, methylammonium iodide, CuSCN, DPS, $PbCl_2$, DMF.

3.2 Construction of DSS cell (FTO/TiO_2/N719/KI-I_2/Pt)

TiO_2 thin film was prepared by mixing the TiO_2 powder in ethanol and coating it by using doctor's blade technique on the conductive glass slide. Heat treatment was done at 450 ˚C for 30 minutes to get an estimated thickness of half micron. The N719 dye was used as photosensitizer. The titania coated thin film glass was kept overnight in a solution of N719 dye and ethanol. This was later rinsed with anhydrous ethanol to remove any unwanted dye. The counter electrode was prepared by coating the platinum paste and annealed at 400 ˚C for one hour. Both the glass slides were placed over one another so that the active cell material lies between them. This was sealed, leaving some space for injection of electrolyte (0.5M KI+0.05M I_2) with the use of spacer. After the electrolyte was injected, the assembly was sealed using epoxy resin. [5,9,14]

3.3 Construction of Perovskite cell (FTO/TiO_2/$CH_3NH_3PbI_3$/CuSCN/C)

Titania was spin coated on conductive glass slide using precursor (0.2M titanium isopropoxide and 0.1M HCl in anhydrous ethanol) at 2000 rpm for 30 seconds. It was put at 450 ˚C for 20 minutes. It was left to cool for 10 minutes. The perovskite precursor was soaked on glass slide for 1 minute and then spin coated at 2000 rpm for 30 seconds. (The perovskite precursor was made using CH_3NH_3I, $PbCl_2$ and DMF) After this sample was placed on preheated plate at 100 ˚C till the film turned black. Black color indicates the formation of the perovskite crystals. Thicker layer and more of iodine content make it look darker. After 10 minutes the temperature was decreased to 80 ˚C. The CuSCN solution was deposited using syringe and left for 15 minutes for the layer to get deposited. Some carbon particle was dropped on the counter electrode and then the two plates were put together by sliding over one another. Sliding was done carefully so that perovskite layer not gets damaged. The two electrodes then were sealed using epoxy resin. [15-17].

4. RESULTS AND DISCUSSION

The maximum current and voltage of both the cells were found by attaching alligator clips to the end of the electrodes and using the circuit given. The TiO_2 side was connected to the black (-ve) terminal and counter was connected to the red (+ve) terminal. The circuit diagram to find the VOC and ISC is shown. The open circuit voltage is measured in parallel and current in series.

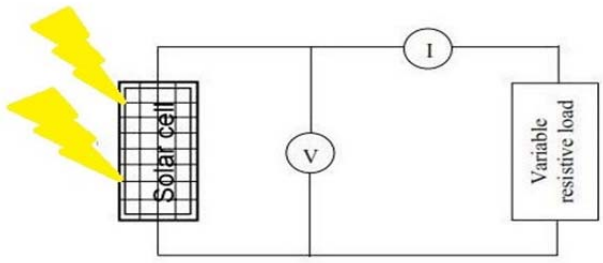

Fig. 5. Circuit diagram for measuring maximum voltage and current.

The cell was illuminated under standard 100mW/cm^2 radiation under AM1.5 filter. For (a)DSSC, the short circuit current ISC=5mA and open circuit voltage VOC=0.591V (b)Perovskite, the short circuit current ISC=2.899mA and open circuit voltage VOC=0.486V were found out. The fill factor was taken to be 60%. The efficiencies were found to be 1.77% and 0.85% respectively.

The structural properties of the titania powder can be found using XRD. The average grain size of sample can be estimated by Scherer's formulae. Optical properties of the TiO_2 powder can be found out by the transmittance spectra and Optical band gap can be found out by Tauc's plot as available in literature.

Efficiency can be found out by formulae $\eta = (ISC*VOC*FF)/P_{in}$

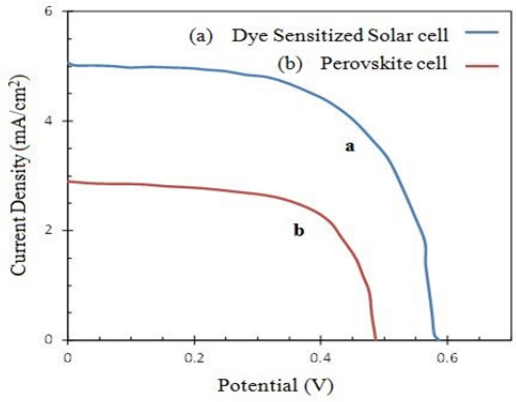

Fig. 6. J-V characteristics of the fabricated DSSC and perovskite solar cells

The efficiencies came out to be low when compared to those reported earlier. The reason for these lower efficiencies is explained.

In the experiment, the blocking TiO_2 layer was not deposited. This blocking layer helps in improving the photon collecting efficiency. This blocking layer can be deposited using spray pyrolysis like technique which leads to higher efficiency.

The efficiency of DSSC can be improved by using better electrolytes. Also the testing should be done just after fabrication to capture the peak efficiency. [5]

In case of perovskite cell, for preparing counter electrode, sputtering or metal evaporator should be used, which requires high vacuum and improves the efficiency drastically. But these require setups with very high initial cost. Also the counter electrode material can be gold or silver to improve the efficiency. In absence of it, platinum paste or carbon particles/nanotubes can be used on counter electrode but at the cost of efficiency. Since carbon particles were used for this purpose, therefore efficiency decreased drastically. [15]

Also the HTM used in perovskite cells for this experiment are the simple CuSCN based. These are not known to be very good at charge transport, when compared to the popular solid state HTM like spiro-MeO-TAD, leading to lower efficiency. [2]

The perovskite is very sensitive to moisture. [2] In presence of moisture the sample performance comes out to be very low. This can be overcome by performing the entire fabrication steps and testing in a standard Glove Box which maintains protected environment inside.

Also more care during the use of epoxy resin for fixing and prevention of scratches can help in improving efficiency.

5. CONCLUSION

In this paper the two most popular 3rd generation cells, DSSC and perovskite, were discussed. Components of these cells were discussed using 3D images. The step by step fabrication of these two cells was explained using schematic diagram. In this paper, simplified version of both the cells was fabricated and efficiency was found out. The reasons for getting lower efficiencies were explained. These two technologies discussed above have the capacity to compete with the conventional solar cells. Narayan [18] mentioned about the materials used in DSSC which are relatively cheaper and abundant in environment. Compared to perovskite cells they are immune to impurities in fabrication process. Perovskite cell requires high end technologies and are extremely prone to humidity and have to be encapsulated. Weight and flexibility of DSSC's are desirable and can be made in different colors unlike perovskite. DSSC's different color can be used for decorative purpose also. But the stability issues for both have to be seen. Some startups have already started producing these cells and are planning to go for mass production within few years.

6. ACKNOWLEDGEMENTS

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List of abbreviations

AM1.5	Air mass 1.5
DSSC	Dye-sensitized solar cell
DMF	Dimethylformamide
DPS	Diphenyl sulfide
FTO	Fluorine-doped tin oxide
HTM	Hole transport material
ITO	Indium-doped tin oxide
N3	cis-Bis(isothiocyanato) bis(2,2'-bipyridyl-4,4'-dicarboxylato ruthenium(II)
N719	Di-tetrabutylammonium cis-bis(isothiocyanato)bis(2,2'-bipyridyl-4,4'-dicarboxylato)ruthenium(II)
Pt-TCO	Platinum coated transparent conductive oxide
spiro-MeO-TAD	2,2',7,7'-Tetrakis-(N,N-di-4-methoxyphenylamino)-9,9'-spirobifluorene
TCO	Transparent conductive oxide

List of symbols

FF (%)	Fill factor
ISC (mA)	Short circuit current
P_{in}	Optical power input
VOC (V)	Open circuit voltage
η (%)	Conversion efficiency of solar cell