RESEARCH ARTICLE OPEN ACCESS

Dye Sysentized Solar Cell (Dyssc)

A. Dileep, Dr. M. Damodar Reddy.
M. Tech, Department of Electrical and Electronics Engineering, S.V. University college of Engineering, Andhra Pradesh-517502, India.
Professor, Department of Electrical and Electronics Engineering, S.V. University college of Engineering, Andhra Pradesh-517502, India.

Abstract
This paper presents a Dye sensitized solar cell (DYSSC), which is called as future generation solar cell. It is a new class of green photovoltaic cell based on photosynthesis principle in nature. DYSSCs are fabricated using two different natural dyes as sensitizers, which extracted from the materials existing in nature and our life, such as flowers, leaves, fruits, traditional Chinese medicines, and beverages. The use of sensitizers having a broad absorption band in conjunction with oxide films of nanocrystalline morphology permits to harvest a large fraction of sunlight. There are good prospects to produce these cells at lower cost and much better efficiency than conventional semiconductor devices by introducing various chemical and natural dyes. DYSSC are implemented with simple and new technique to overcome the energy crisis and excess cost of semiconductor solar cells.
Key Words: Dye sensitized solar cell, Dyes, Nanocrystalline oxide, semiconductor films, Solar light energy conversion.

I. Introduction

A dye-sensitized solar cell (DYSSC, DSC or DYSC) [1] is a low-cost solar cell belonging to the group of thin film solar cells [2]. It is based on a semiconductor formed between a photo-sensitized anode and an electrolyte, a *photo electrochemical* system. The modern version of a dye solar cell, also known as the Grätzel cell, was originally co-invented in 1988 by Brian O'Regan and Michael Grätzel at UC Berkeley [3] and this work was later developed by the aforementioned scientists at the École Polytechnique Fédérale de Lausanne until the publication of the first high efficiency DYSSC in 1991 [4]. Michael Grätzel has been awarded the 2010 Millennium Technology Prize for this invention [5]. The DYSSC has a number of attractive features; it is simple to make using conventional roll-printing techniques, is semi-flexible and semi-transparent which offers a variety of uses not applicable toglass-based systems, and most of the materials used are low-cost. In practice it has proven difficult to eliminate a number of expensive materials, notably platinum and ruthenium, and the liquid electrolyte presents a serious challenge to making a cell suitable for use in all weather. Although its conversion efficiency is less than the best thin-film cells, in theory its price/performance ratio should be good enough to allow them to compete with fossil fuel electrical generation by achieving grid parity. Commercial applications, which were held up due to chemical stability problems [6], are forecast in the European Union Photovoltaic Roadmap to significantly contribute to renewable electricity generation by 2020.Hence, in this paper DYSSC are implemented with simple and new technique to overcome the energy crisis and excess cost of semiconductor solar cells.

II. Current technology: semiconductor solar cells.

In a traditional solid-state semiconductor, a solar cell is made from two doped crystals, one doped with n-type impurities (n-type semiconductor), which add additional free conduction band electrons, and the other doped with p-type impurities (p-type semiconductor), which add additional electron holes. When placed in contact, some of the electrons in the n-type portion flow into the p-type to “fill in” the missing electrons, also known as electron holes. Eventually enough electrons will flow across the boundary to equalize the Fermi levels of the two materials. The result is a region at the interface, the p-n junction, where charge carriers are depleted and/or accumulated on each side of the interface. In silicon, this transfer of electrons produces a potential barrier of about 0.6 to 0.7 V [7].

In any semiconductor, the band gap means that only photons with that amount of energy, or more, will contribute to producing a current. In the case of silicon, the majority of visible light from red to violet has sufficient energy to make this happen. Unfortunately, higher energy photons, those at the blue and violet end of the spectrum, have more than enough energy to cross the band gap; although some of this extra energy is transferred into the electrons, the majority of it is wasted as heat. Another issue is that in order to have a reasonable chance of capturing a photon, the n-type layer has to be fairly thick. This also increases the chance that a freshly ejected electron will meet up with a previously created hole in the material before reaching the p-n junction. These effects produce an upper limit on the efficiency of silicon solar cells, currently around 12 to 15% for common modulesand up to 25% for the best laboratory cells (About 30% is the theoretical maximum efficiency for single band gap solar cells, see Shockley–Queisser limit.).

By far the biggest problem with the conventional approach is cost; solar cells require a relatively thick layer of doped silicon in order to have reasonable photon capture rates, and silicon processing is expensive. There have been a number of different approaches to reduce this cost over the last decade, notably the thin-film approaches, but to date they have seen limited application due to a variety of practical problems. Another line of research has been to dramatically improve efficiency through the multi-junction approach, although these cells are very high cost and suitable only for large commercial deployments. In general terms the types of cells suitable for rooftop deployment have not changed significantly in efficiency, although costs have dropped somewhat due to increased supply.

III. Dye-sensitized solar cells

In the late 1960s it was discovered that illuminated organic dyes can generate electricity at oxide electrodes in electrochemical cells. In an effort to understand and simulate the primary processes in photosynthesis the phenomenon was studied at the University of California at Berkeley with chlorophyll extracted from spinach (biomimetic or bionic approach) [9]. On the basis of such experiments electric power generation via the dye sensitization solar cell (DYSSC) principle was demonstrated and discussed in 1972 [10]. The instability of the dye solar cell was identified as a main challenge. Its efficiency could, during the following two decades, be improved by optimizing the porosity of the electrode prepared from fine oxide powder, but the instability remained a problem [11]. A modern DYSSC is composed of a porous layer of titanium dioxide nanoparticles, covered with a molecular dye that absorbs sunlight, like the chlorophyll in green leaves. The titanium dioxide is immersed under an electrolyte solution, above which is a platinum based catalyst. As in a conventional alkaline battery, an anode (the titanium dioxide) and a cathode (the platinum) are placed on either side of a liquid conductor (the electrolyte).

Sunlight passes through the transparent electrode into the dye layer where it can excite electrons that then flow into the titanium dioxide. The electrons flow toward the transparent electrode where they are collected for powering a load. After flowing through the external circuit, they are re-introduced into the cell on a metal electrode on the back, flowing into the electrolyte. The electrolyte then transports the electrons back to the dye molecules.

Dye-sensitized solar cells separate the two functions provided by silicon in a traditional cell design. Normally the silicon acts as both the source of photoelectrons, as well as providing the electric field to separate the charges and create a current. In the dye-sensitized solar cell, the bulk of the semiconductor is used solely for charge transport, the photoelectrons are provided from a separate photosensitive dye. Charge separation occurs at the surfaces between the dye, semiconductor and electrolyte.

The dye molecules are quite small (nanometre sized), so in order to capture a reasonable amount of the incoming light the layer of dye molecules needs to be made fairly thick, much thicker than the molecules themselves. To address this problem, a nanomaterial is used as a scaffold to hold large numbers of the dye molecules in a 3-D matrix, increasing the number of molecules for any given surface area of cell. In existing designs, this scaffolding is provided by the semiconductor material, which serves double-duty.

3.1. Construction and Operation:

In the case of the original Grätzel and O'Regan design, the cell has 3 primary parts. On top is a transparent anode made of Indium-doped tin dioxide deposited on the back of a (typically glass) plate. On the back of this conductive plate is a thin layer of titanium dioxide (TiO_2), which forms into a highly porous structure with an extremely high surface area. TiO_2 only absorbs a small fraction of the solar photons (those in the UV) [12]. The plate is then immersed in a mixture of a photosensitive such as turmeric and pomegranate dye (also called Natural sensitizers) [12] and a solvent. After soaking the film in the dye solution, a thin layer of the dye is left covalently bonded to the surface of the TiO_2. A separate plate is then made with a thin layer of the iodide electrolyte spread over a conductive sheet, typically platinum metal. The two plates are then joined and sealed together to prevent the electrolyte from leaking.

The construction is simple enough that there are hobby kits available to hand-construct them [13]. Although they use a number of “advanced” materials, these are inexpensive compared to the silicon needed for normal cells because they require no expensive manufacturing steps. TiO2, for instance, is already widely used as a paint base. One of the efficient DYSSC devices uses ruthenium based molecular dye, e.g. [Ru (4,40-dicarboxy-2,20- bipyridine)2(NCS)2] (N3), that is bound to a photo anode via carboxylate moieties. The photo anode consists of 12 μm thick film of transparent 10–20 nm diameter TiO2 nanoparticles covered with a 4 μm thick film of much larger (400 nm diameter) particles that scatter photons back into the transparent film. The excited dye rapidlyinjects an electron into the TiO2 after light absorption.

The injected electron diffuses through the sintered particle network to be collected at the front side transparent conducting oxide electrode, while the dye is regenerated via reduction by a redox shuttle, I3/I, dissolved in a solution. Diffusion of the oxidized form of the shuttle to the counter electrode completes the circuit.

Operation:

Sunlight enters the cell through the transparent ITO top contact, striking the dye on the surface of the TiO2. Photons striking the dye with enough energy to be absorbed create an excited state of the dye, from which an electron can be "injected" directly into the conduction band of the TiO2. From there it moves by diffusion (as a result of an electron concentration gradient) to the clear anode on top. Meanwhile, the dye molecule has lost an electron and the molecule will decompose if another electron is not provided.

The dye strips one from iodide in electrolyte below the TiO2, oxidizing it into triiodide. This reaction occurs quite quickly compared to the time that it takes for the injected electron to recombine with the oxidized dye molecule, preventing this recombination reaction that would effectively short-circuit the solar cell. The triiodide then recovers its missing electron by mechanically diffusing to the bottom of the cell, where the counter electrode re-introduces the electrons after flowing through the external circuit.

3.2. Efficiency, Test results and Implementation of DYSSC:

Several important measures are used to characterize solar cells. The most obvious is the total amount of electrical power produced for a given amount of solar power shining on the cell. Expressed as a percentage, this is known as the *solar conversion efficiency*. Electrical power is the product of current and voltage, so the maximum values for these measurements are important as well, Jsc and Voc respectively. Finally, in order to understand the underlying physics, the "quantum efficiency" is used to compare the chance that one photon (of a particular energy) will create one electron. In quantum efficiency terms, DYSSCs are extremely efficient.

Due to their "depth" in the nanostructure there is a very high chance that a photon will be absorbed, and the dyes are very effective at converting them to electrons. Most of the small losses that do exist in DSSC's are due to conduction losses in the TiO2 and the clear electrode, or optical losses in the front electrode. The overall quantum efficiency for green light is about 90%, with the "lost" 10% being largely accounted for by the optical losses in top electrode. The quantum efficiency of traditional designs varies, depending on their thickness, but are about the same as the DYSSC.

In theory, the maximum voltage generated by such a cell is simply the difference between the (*quasi*-)Fermi level of the TiO2 and the redox potential of the electrolyte, about 0.7 V under solar illumination conditions (Voc). That is, if an illuminated DYSSC is connected to a voltmeter in an "open circuit", it would read about 0.7 V. In terms of voltage, DSSCs offer slightly higher Voc than silicon, about 0.7 V compared to 0.6 V. This is a fairly small difference, so real-world differences are dominated by current production, Jsc. Although the dye is highly efficient at converting absorbed photons into free electrons in the TiO2, only photons absorbed by the dye ultimately produce current. The rate of photon absorption depends upon the absorption spectrum of the sensitized TiO2 layer and upon the solar flux spectrum.

The overlap between these two spectra determines the maximum possible photocurrent. Typically used dye molecules generally have poorer absorption in the red part of the spectrum compared to silicon, which means that fewer of the photons in sunlight are usable for current generation. These factors limit the current generated by a DYSSC, for comparison, a traditional silicon based solar cell offers about 35 mA/cm2, whereas current DYSSC offer about 20 mA/cm2. Overall peak power conversion efficiency for current DYSSC is about 11% [15] [16]. Current record for prototypes lies at 15% [17] [18].

- Efficiency of a Solar cells can be calculated using

$$\eta = \frac{Pm}{G * Ac}$$

Pm=Maximum Power Point.
G in W/m^2 (Standard 1000 W/m^2).
$A_{c\ in\ m}^2$ (Surface Area of cell).

- Maximum Efficiency of a solar cell can be called as

$$\eta max = \frac{Pmax}{Es.r * Ac}$$

Ac = Area of collector
Es. r =Incident of radiation flux (1000 W/m^2)
P_{max} = Maximum power point.

Implemented DYSSC:
The below Figure 1 shows the complete DYSSC which is both its positive and negative channels are combined with the help of clip.

Fig 1: Image represents the Practical DYSSC

The below Figure 2 shows the whole assembly set of DYSSC which is connected in series to multimeter for testing voltage and current purpose.

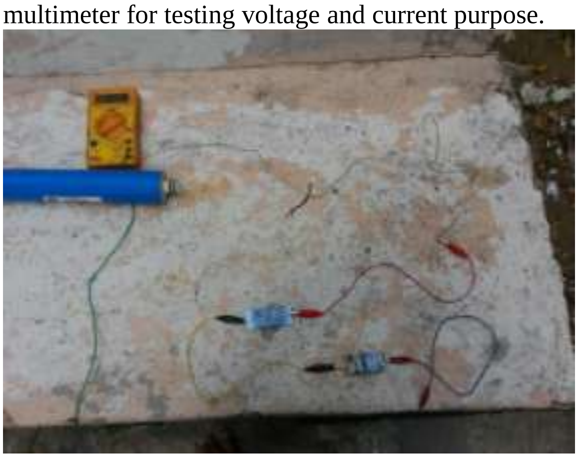

Fig 2: Image represents the whole assembly set of DYSSC.

Test Results of DYSSC:
- Single cell requires two ITO glass slides or FTO glass slides which is used as an electrode.
- Size of the current prototype is taken as 50*25mm.

AREA=12.5m^2 (1,25,000cm^2)
- Basic power equation used to know the amount of power generated is taken as

P=V*I
- ITO=Indium Tin Oxide Coated Glass.
- Reading taken for 6 intervals of time period using **Turmeric Dye**.

Table 1: The below table gives the results of when DYSSC is tested using Turmeric Dye.

Time	**Voltage (mv)**	**Current (μA)**	**Power (W)**
11.05 AM	25mv	13μA	$3.25*10^{-7}$
11.35AM	31.9mv	27μA	$80613*10^{-7}$
12.05PM	30.6mv	25μA	$7.65*10^{-7}$
12.35PM	28.4mv	22μA	$6.248*10^{-7}$
1.05PM	27.9mv	21μA	$5.859*10^{-7}$
1.35PM	27.5mv	21μA	$5.775*10^{-7}$

Note: Sunlight not constant Peak Voltage=40mv

- Reading taken for 6 intervals of time period using **Pomegranate Dye**.

Table 2: The below table gives the results of when DYSSC is tested using Pomegranate Dye.

Time	**Voltage (mv)**	**Current (μA)**	**Power (W)**
11.00AM	30 mv	17μA	$5.1*10^{-7}$
11.30AM	29 mv	25μA	$7.25*10^{-7}$
12.00PM	35mv	29μA	$1.01*10^{-6}$
12.30PM	43mv	30μA	$1.29*10^{-6}$
1.00PM	39mv	32μA	$1.24*10^{-6}$
1.30PM	45mv	33μA	$1.48*10^{-6}$

Note: Sunlight Not Constant Peak Voltage=60mv

3.3. Advantages and Disadvantages:

Presently DYSSC are the most efficient solar cell technology available. The efficiency of the thin film technology is typically between 5%-13% and traditional semiconductor solar cells are 14%-17%. The maximum efficiency of the semiconductor solar cells till date noted is 46%. The main advantage of the DYSSC are, it can be replaced easily in the place of silicon solar cells to reduce the cost of the system and also DYSSC are light in weight to handle. But, this type of cells is not very useful for the large type of system due to its high cost. Hence as a result the DYSSC works better even in low light environmental condition when compared to thin film technology. There are lot of methods to increase the efficiency of the DYSSC but one of them is that the cells are tightly sealed or packed in a glass box to increase the efficiency and robustness of the system. Due to this the system can work under lower internal temperatures.

The cut-off is so low they are even being proposed for indoor use, collecting energy for small devices from the lights in the house [18]. The major practical advantage, one DYSSC share with thinnest film technologies, is that the cell's mechanical robustness indirectly leads to higher efficiencies in higher temperatures.

Disadvantages:

The major disadvantage to the DYSSC design is the use of the liquid electrolyte, which has temperature stability problems. At low temperatures the electrolyte can freeze, ending power production and potentially leading to physical damage. Higher temperatures cause the liquid to expand, making sealing the panels a serious problem. Another disadvantage is that costly ruthenium (dye), platinum (catalyst) and conducting glass or plastic (contact) are needed to produce a DYSSC. A third major drawback is that the electrolyte solution contains volatile organic compounds (or VOC's), solvents which must be carefully sealed as they are hazardous to human health and the environment.

This, along with the fact that the solvents permeate plastics, has precluded large-scale outdoor application and integration into flexible structure [19]. Replacing the liquid electrolyte with a solid has been a major ongoing field of research. Recent experiments using solidified melted salts have shown some promise, but currently suffer from higher degradation during continued operation, and are not flexible [20].

IV. Recent Development

During the last 5-10 years, a new kind of DYSSC has been developed - the solid state dye-sensitized solar cell. In this case the liquid electrolyte is replaced by one of several solid hole conducting materials. From 2009 to 2013 the efficiency of Solid State DYSSCs has dramatically increased from 4% to 15%. Michael Grätzel announced the fabrication of Solid State DYSSCs with 15.0% efficiency, reached by the means of a hybrid perovskite $CH_3NH_3PbI_3$ dye, subsequently deposited from the separated solutions of CH_3NH_3I and PbI_2 [21].

V. Conclusions

DYSSC implemented and tested with two different natural dyes, which is used to compare the dyes and to test the performance of the cells with environmental changes. Hence from the results we can say that the performance of the pomegranate dye having much better voltage and current values than the turmeric dye. Hence, it has opened up new dimensions for solar cell technology. Research is going on to develop efficient DYSSC to compete the conventional silicon based solar cells. From last few years' great progress has been made on various aspects including efficiency, stability and commercialization. These developments can lead the basis for globalization of DYSSC. Also DYSSC due to its attractive features like low cost, ease of production, transparency and good performance under typical conditions (temperature and illumination conditions) is proving itself better than Si- based cells, irrespective of its low efficiencies.

But there are new techniques and ideas, studies have resulted in the better performance of DYSSC. DYSSC has an efficiency up to 20% has been achieved, which has opened up a new scope for further research on various aspects of DYSSC. Recently DYSSC is efficient when it is using a new perovskite based mineral. It has attracted much attraction due to its simple fabrication and greater efficiency up to 17%. Also work is going on for developing solar cells with efficiency up to 50% too.

Hence due to its effectiveness and simplicity, it is expected that the low cost for commercially fabricating dyssc along with its good performance will definitely replace conventional solar cells very sooner. Still researches are going on for improving the efficiency and viability of the cell, these include the use of efficient photo sensitizers dyes for the conversion of higher-energy (higher frequency) light into multiple electrons, using solid-state electrolytes for better temperature response, and changing the doping of the TiO_2 to better match it with the electrolyte being used. Finally, although there have been a number of initial studies into the development of DYSSC modules, a thorough understanding of overall efficiencies, life times and degradation mechanisms of new efficient stable DYSSC.

References

[1] Wan, Haiying"Dye Sensitized Solar Cells", University of Alabama Department of Chemistry, p. 3

[2] "Dye-Sensitized vs. Thin Film Solar Cells", European Institute for Energy Research, 30 June 2006

[3] EarlyHistory. Workspace.imperial.ac.uk. Retrieved on 30 May 2013.

[4] Brian O'Regan, Michael Grätzel (24 October 1991). "Alow-cost, high-efficiency solar cell based on dye-sensitizedcolloidal TiO2 films". *Nature* **353** (6346): 737–740. Bibcode:1991 Nature. 353..737O. doi:10.1038/353737a0.

[5] Professor Grätzel wins the 2010 millennium technology grand prize for dye-sensitized solar cells, TechnologyAcademy Finland, 14 June 2010.

[6] Tributsch, H (2004). "Dye sensitization solar cells: a critical assessment of the learning curve". *CoordinationChemistry Reviews* **248** (13–14): 1511. doi: 10.1016/j.ccr.2004.05.030.

[7] "Photovoltaic Cells (Solar Cells), How They Work". specmat. com. Retrieved 22 May 2007.

[8] Gerischer, H.; Michel-Beyerle, M.; Rebentrost, E.; Tributsch, H. (1968). "Sensitization of Charge-Injection into Semiconductors with Large Band Gap". *ElectrochemicalActa***13** (13): 1509–1515. doi:10.1016/0013-4686(68)80076-3.

[9] Tributsch, H.; Calvin, M. (1971). "Electrochemistry of Excited Molecules: Photo electrochemical Reactions of Chlorophylls". *Photochem. Photobiol.* **14** (14): 95–112.doi:10.1111/j.1751-1097. 1971.tb06156. x.

[10] Tributsch, H. (1972). "Reaction of Excited Chlorophyll Molecules at Electrodes and in Photosynthesis". *Photochem.Photobiol.* **16** (16): 261–269.doi:10.1111/j.1751-1097. 1972.tb06297. x.

[11] Matsumura, M.; Matsudaira, S.; Tsubomura, H.; Takata, M.; Yanagida, H. (1980). "Dye Sensitization and Surface Structures of Semiconductor Electrodes". *Ind.Eng. Chem. Prod. Res. Dev.* **19** (3): 415–421. doi:10.1021/i360075a025.

[12] Juan Bisquert, "Dye-sensitized solar cells", Department de Física, UniversitatJaume I

[13] "Dye Solar Cell Assembly Instructions". Solar nix. Retrieved 22 May 2007.

[14] Hamann, W.T, Jensen, A.R, Martinson, A, Ryswykac, H and Hupp, J (2008). "Advancing beyond current generation dye-sensitized solar cells". *Energy Environ. Sci.* **1**: 66–78. doi:10.1039/b809672d.

[15] American Chemical Society, "Ultrathin, Dye-sensitized Solar Cells Called Most Efficient to Date", *ScienceDaily*,20 September 2006

[16] Gao, F; Wang, Y; Zhang, J; Shi, D; Wang, M; Humphry- Baker, R; Wang, P; Zakeeruddin, Sm; Grätzel, M (2008). "A new heteroleptic ruthenium sensitizer enhances the absorptivity of mesoporous titania film for a high efficiency dye-sensitized solar cell". *Chemicalcommunications*(23):2635–7doi:10.1039/b802909a. PMID 18535691.

[17] press release of EPFL

[18] Nature: Sequential deposition as a route to high performance perovskite-sensitized solar cells. doi:10. 1038/nature12340.

[19] École Polytechnique Fédérale de Lausanne, "New Efficiency Benchmark for Dye-sensitized Solar Cells", *Science Daily*,3 November 2008

[20] Nathalie Rossier-Iten, "Solid hybrid dye-sensitized solar cells: new organic materials, charge recombination and stability", École Polytechnique Fédérale de Lausanne,2006

[21] Nature: Sequential deposition as a route to high performance perovskite-sensitized solar cells. doi:10. 1038/nature12340.