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A Brief Review on Dye Sensitized Solar Cells

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Abstract: Photo-voltaic (PV) devices such as a Dye-Sensitized Solar Cell (DSSC) is a source of energy that converts incident photon or solar radiation to usable electricity. DSSCs are fast becoming a viable and interesting alternative to the traditional inorganic photo-voltaic devices to address the demerits of the inorganic PV devices like the use of expensive noble metals and high-cost chemical synthesis processes. A DSSC functions with two main components, i.e., a photo-sensitizer that absorbs incident light and a semiconductor onto which it is adhered to and a conductive glass housing such as Florine-doped Tin Oxide (FTO) or Indium-doped Tin Oxide (ITO), between which the sensitizer, semiconductor and an electrolyte are sandwiched. The semiconductor is preferably a wide-band semiconductor, of which the commonly used semiconductors in a DSSC are made of a nanoparticle layer of Titanium dioxide (TiO_2), Zinc oxide (ZnO) and Tin oxide (SnO_2). The utility of these solar cells with a diverse number of natural photo-sensitizers for use as an alternative PV device is described. Currently, there are an abundance of natural sources that could be used to obtain photo-sensitizers from, such as, micro and macro algae, plants, bacteria, etc. leading to increased importance in renewable energy sector and has gained traction to be a viable renewable energy resource. In addition to the functioning of an organic DSSC, various characteristics of the pigments used as photo-sensitizers are described here. Patents filed regarding eco-friendly and natural Dye-Sensitized Solar Cells have been increasing as of late and holds substantial promise.

Keywords: Photo-Voltaic, Dye-Sensitized Solar Cell, Photo-sensitizer, Conductive glass, TiO_2

I. INTRODUCTION

A. Overview of DSSC

Dye-Sensitized Solar Cells are based on the use of colored dyes as photosensitizers, which are able to harness the energy coming from the Sun in the form of solar radiation in the visible spectrum [42]. They contain a nano-porous oxide layer as the main component of the cell, normally composed with titanium dioxide (TiO_2) acting as a semiconductor medium [3]. The dye that is applied to this TiO2 monolayer film is absorbed on its surface. When this pigment is photoexcited, electrons are injected into the titanium dioxide film's conduction band. Electron donation from the electrolyte solution, where a redox system such as the iodide/triiodide pair is present, then restores the dye. The iodide is then regenerated at the counter electrode, which is commonly built on a platinum substrate, by reducing triiodide, and the circuit is then completed by electrons migrating that occurs at the external load [2]. Solar cells are divided into three generations: first, second, and third. The third-generation solar cells strive to reduce cost while increasing efficiency, while first-generation solar cells have a high cost and second-generation solar cells have a poor efficiency. Dye Sensitized Solar Cells (DSSC), polymer cells, and hot carrier cells make up the majority of third-generation solar cells [25]. The sensitizer allocated to DSSC must have three integral characteristics to facilitate maximum absorption efficiency. The sensitizer is ideally required to be black, with exceptionally high absorption in the UV-A, visible, and IR spectral regions. Electron transmission from the sensitizer that has been excited due to incident light, to the photoanode must be quick and efficient and the photostability of the sensitizer must be in such a way that the material must be able to withstand several oxidation-reduction cycles without the sensitizer breaking down [39], [3].

B. History of a Dye Sensitized Solar Cell

Dye Sensitized Solar Cells (DSSC) have had an explosive growth since they were developed by [41] nearly thirty years ago. In the beginning, they were based on natural dyes, as those used by plants in photosynthesis. They use organic dyes to harvest the incident light, leading a flow of electrons. The first clear recognition and verification of operating principles of a DSSC goes back to the 1960s, when [40] researched a ZnO photoelectrode sensitized by organic dyes.

They found that these cells had low efficiency and lower conversion of photon-to-current, because for the photoelectrode they had used single crystals and polycrystalline materials [40]. After the introduction of nanoparticles such as TiO_2, which are mesoporous and synthesized dyes, the performance of these cells showed improvement [39].

Over the past few years, research on the topic has significantly increased driven by the motivation of finding new forms of energy. Nevertheless, the reported efficiencies remain low (at around 12%). In this regard, the use of natural dyes might represent an attractive and cheap alternative.

Especially in the developing countries it is a great alternative to synthetic commercial reactants. It has been reported that natural dyes-based-cells showed efficiencies values up to 2% and with good stability [5].

Macroalgal species have shown a broad range of applications and their importance in several sectors have grown increasingly worldwide. Aquaculture industries produced 15.8 million tons of aquatic plants, with a total estimated value of US$ 7.4 billion according to a study performed by FAO (The Food and Agriculture Organization of the United Nations). Out of which, 47% of the total production is used for human consumption, 43% in the extraction of colloids, 7% in the production of Maerl and the rest, in the fields of pharmacology, cosmetics, agriculture and waste water treatments from aquaculture, sewage, agricultural and industrial run-off. Algal biomass is also an important resource used in the field of renewable energies for the production of biogas. However, macroalgae still remains an underexploited resource in the photovoltaic technology background [6].

C. Structure of DSSC

The physical processes that support a DSSC's function set it apart from conventional solar cell systems. The conventional DSSC layout blends liquid and solid phases, in contrast to first- and second-generation Photo-Voltaic devices based on solid-state semiconductor semiconductors. A transparent conducting glass electrode (anode) permits light to travel through the cell in a DSSC. Because of their inexpensive cost, availability, and excellent transparency in the visible spectrum, clear glass substrates are commonly utilized as electrode substrates [22]. Transparent conductive glasses are commonly made up of either fluorine doped tin oxide or indium doped tin oxide. For optimal solar cell functioning, such conductive glasses should be low in resistance and high in transparency. Transparent conductive glasses serve as the photoelectrode's substrate, by allowing light to pass through while also collecting electrons for transmission to the external circuit. To aid sintering of electrodes, it should be stable up to 450°–500° C. Metal oxide nanoparticles such as TiO_2, ZnO, and SnO_2 are deposited on conducting glass to form a photoelectrode. The largest surface area for dye molecule absorption is provided by nano-porous photo electrodes. Electron transport from dye to the conducting surface is aided by the electrode's porosity [4],[35]. To allow maximum chemisorption, the photoanode is submerged in dye solution and thereby produces a sensitized nano-porous electrode. Because electron transmission from the photoanode to the electrolyte is slower than from the counter cathode to the electrolyte, iodine/triiodide is a typical electrolyte [35]. Depositing Platinum on the conductive glass creates the counter electrode (cathode), which is then treated to create Platinum colloids. Graphite can also be utilized as a counter-electrode. Electrodes and electrolyte are sealed with an electrolyte- and irradiation-resistant substance [25].

D. Working of DSSC

Photon absorption in the DSSC is achieved by dye molecules sensitised on the photoanode. When a dye is photo-excited, electrons are excited and jumps to a higher energy state forming an intermediary high energy entity within the molecules of the dye. The difference in energy levels between the molecules that are a part of the dye and acceptor's conduction band, i.e., nanoparticle layer gives rise to the force to separate the electron hole pair, forming a potential gradient. The conducting glass surface collects the electrons and are then transmitted to the external load, converting light energy into electrical energy. [22] In order to regenerate for the next operation cycle, oxidised dye is reduced by I-ions from the electrolyte. Ions are, however, oxidised to I3-ions during this process. The counter electrode collects the electron and reduces the I3-ions. Without any net chemical change, the operation cycle is finished. [25] [26]

E. Desirable Properties

Inorganic semiconductor nanoparticles have generally been exploited with regards to its varying optical characteristics. To achieve greater photon absorption and improved I_{sc} (short-circuit current), a minimal band gap is necessary and results in maximum utilization of solar energy in the visible spectrum. [25] For optimal dye adsorption, the nanostructured semiconductor particles should have a large enough surface area. The photoanode must have a high charge carrier mobility in order to efficiently capture photogenerated electrons. All the above materials make the DSSC a desirable alternative. The DSSC also has semi-transparency with good light diffusivity that makes it an attractive alternative. [36] simplicity of preparation, stability, cheap cost, and environmental friendliness are some of the other significant features of the materials that are desirable. An ideal photoanode has these features [27], [43].

F. DSSC as an Alternative

Paula Enciso and María Fernanda Cerdá (2016) [2], from their work on the Antarctic red algae containing phycoerythrin list characteristics of the pigment such as, maximum absorption band at 550 nm having a high molar decadic absorption coefficient value (ca. 10^5 M^{-1} cm^{-1}) as well as an abundancy in the southern seawaters. Phycoerythrin is responsible for the red color of the algae. They also state that the use of such a dye-sensitized solar cell with phycoerythrin as a sensitizer could be beneficial at a location such as Antarctica, since phycoerythrin is able to harvest sunlight even in poorly lit conditions and therefore, it could offer partial energy solutions in Antarctica. Chlorophylls based-dyes obtained from seaweeds represent attractive alternatives to the expensive and polluting pyridyl based Ruthenium complexes because of their abundance in nature. Another important characteristic is that the algae do not subtract either cropland or agricultural water, therefore do not conflict with agro-food sector. Using seaweed as an alternative for the DSSC is an inexpensive substitute to more commercially used dyes. The seaweed collected in Venice lagoons and the pigments of chlorophyll c were extracted using acetone/water extraction procedures to obtain viable alternate results [24].

Antonio *etal* (2018) [5] lists three types of DSSCs as commonly found and used, i.e., ruthenium (II) polypyridyl complexes, Zn-porphyrin derivatives and metal-free organic dyes and have based their research on the exploration of their third type, i.e., metal-free organic dyes. Seaweeds and marine planktons are one of the most abundant photosynthetic species containing the c type of chlorophyll and hence exploiting them have been a topic of interest lately. Wang *etal* (2007) [6] have used the pigments Chlorophyll c1 and Chlorophyll c2 and mention that they have a terminal carboxyl group connected to a porphyrin macrocycle through a conjugated double bond and hence state that they have potential to efficiently inject electron from the porphyrin macrocycle to TiO_2.Several previously explored research on the DSSC suggest the necessity of the replacement of synthetic dyes with organic dye for the purpose of altering the chemical structure with required properties like redox potential, band gap and temperature stability. Modification of chemical structure of the chlorophyll macromolecule by insertion of an ethynyl group between the carboxy group and chlorine π-skeleton showed an enhancement in the efficiency of DSSC and hence the viable alternative nature of using natural dyes was explored [7].

II. DSSC ASSEMBLED USING VARIOUS PIGMENT SOURCES

DSSCs assembled with the usage of organic dyes as photo-sensitizers can have distinct and various sources from algal, plant, or microbial sources. The cells assembled with such organic dyes from plant sources like radish, beetroot have achieved efficiencies of 1.41% [29] and 2.7% [30] respectively.

The table given below (Table 1) lists some of the sources and the components used for the assembly of a Dye Sensitized Solar Cell.

Table I: DSSCs assembled using various pigment sources

SOURCE	PIGMENT	PHOTOANODE	CATHODE	ELECTROLYTE	REFERENCES
Brown seaweed (Undaria pinnatifida)	Chlorophyll	FTO glass paste with TIO_2nanoparticles	Pt coated surface	LiI 0.8 M, I_2 0.05 M, in acetonitrile	Giuseppe Calogero et al, 2013 [24]
Iridaeaobovate, Delesseria lancifolia, Plocamium hookeri	Phycocyanin phycoerythrin chlorophyll	FTO glass paste with TIO_2nanoparticles	Pt coated surface	Iodide/tri-iodide couple	Paula Enciso et al, 2018 [2]
Undaria pinnatifida	Chl c1 Chl c2 Chl c01 Chl c02	FTO glass paste with TIO_2nanoparticles	Pt coated surface	Iodide/tri-iodide couple	Xiao-Feng Wang et al, 2007 [6]
Rose petals	Anthocyanin	FTO glass paste with TIO_2nanoparticles	Pt coated surface	Iodide/tri-iodide couple	N. Prabavathy et al, 2017 [9]
Porphyridium cruentum	Phycobiliproteins	FTO glass paste with TIO_2 nanoparticles	Pt coated surface	0.5 mol/L LiI, 0.05 mol/L I_2, 0.3 mol/L DMPII, 0.5 mol/L 4-TBP and 0.1 mol/L GNCS in acetonitrile	Wenjun Li et al, 2018 [34]

Hymenobacter actinosclerus, Chryseobacterium chaponense	Carotenoid bacterial pigments	FTO glass paste with TIO_2 nanoparticles	Pt coated surface	Iodide/tri-iodide couple	Ordenes-Aenishanslins N et al, 2016 [15]
Celosia Cristata	Pigment mixture	FTO glass paste with TIO_2 nanoparticles	Pt coated surface	acenonitrile-ethylenecarbonate containing 0.5 mol dm−3 tetrabutyl ammonium iodide	M. Hosseinnezhad et al, 2018 [16]
Amaranthus tricolour L	Chlorophyll	FTO glass paste with TIO_2 nanoparticles	Pt coated surface	0.6 M 4-butyl methyl imidazolium iodide (BMII), 0.04 M Iodine (I2), 0.1 M lithium iodide (LiI), 0.1 M guanidium thiocyanate (GuSCN) and 0.5 M tertiary butyl pyridine in acetonitrile	R Ramanarayanan et al, 2017 [17]
Malva verticillata, Enteromorpha, Suaeda aegyptiaca, Sargassum, Garcilaria	Chlorophyll, Flavonoid, Fucoxanthin, Phycoerythrin	FTO glass paste with TIO_2 nanoparticles	Pt coated surface	Iodide/tri-iodide couple	Malihe Golshan et al, 2019 [18]
Murraya Koenigii Fruit, Hibiscus Sabdarifa Flower	Pigment mixture	FTO glass paste with TIO_2 nanoparticles	Pt coated surface	Idolyte TG 50	S.Rajkumar et al, 2019 [19]
Cordyline fruticosa, Hylocereus polyrhizus	Chlorophyll, Anthocyanin, betalains	FTO glass paste with TIO_2 nanoparticles	Pt coated surface	0.5 M potassium iodide mixed with 0.05 M iodine dissolving in the solution of ethylene glycol + acetonitrile	C Silva et al, 2019 Patricia Hernández-Velasco et al, 2020 [20], [21]
Blackberry, Blueberry, cherry, raspberry, strawberry	Anthocyanin	FTO glass paste with TIO_2 nanoparticles	Pt coated surface	Iodide/tri-iodide couple	Mahmoud A.M.Al-Alwani et al, 2017 [22]

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III. METHODS USED IN DSSC AND ITS CHARACTERISTICS

The first clear recognition and verification of operating principles of a DSSC goes back to the 1960s, when Gerisher and Tributsh researched a ZnO photoelectrode sensitized by organic dyes. They found that these cells had low efficiency and lower conversion of photon-to-current, because for the photoelectrode they had used single crystals and polycrystalline materials. After the introduction of nanoparticles such as TiO_2, which are mesoporous and synthesized dyes, the performance of these cells showed improvement [39]. Glass can be used as the support substrate however a flexible plastic substrate can also be used. Because light passes into the cell through the support substrate, it must be transparent in the visible and near UV regions. A thin coating of a transparent, conducting substance is placed on the inner surface of the support substrate to form the anode [36].

The following table provides some of the types of methods used in preparing a functional DSSC. (Table 2)

Table II: Methods used in DSSC and its characteristics

SOURCE	PIGMENT	METHODS USED	EFFICIENCY	CURRENT DENSITY (MA/CM^2)	VOLTAGE (V)	REFERENCES
Undaria pinnatifida	Chlorophyll	UV–Vis spectrophotometer, IPCE station, LOT-Oriel solar simulator,	0.178%	0.8	0.36	Giuseppe Calogero *etal 2013 [24]*
Plocamium hookeri, Delesseria lancifolia and Iridaea obovata	Phycocyanin phycoerythrin chlorophyll	Electrochemical impedance spectroscopy. UV-vis spectrophotometry, Potentiostat, Solar simulator.	0.027% 0.045% 0.022%	0.083 0.243 0.136	0.53 0.4 0.4	Paula Enciso *etal 2016 [2]*
Undaria pinnatifida	Chlorophyll c1 Chlorophyll c2 Chlorophyll c1' Chlorophyll c2'	Mass spectrometry, ^{1}H NMR spectroscopy	3.4% 4.6% 2.5% 2.6%	10.7 13.8 8.6 9.0	0.53 0.57 0.47 0.47	Xiao-Feng Wang *etal 2007 [6]*
Porphyridium cruentum	phycobiliproteins	Confocal laser scanning electron microscopy, Scanning electron microscopy	1%	3.236	0.545V	Wenjun Li *etal, 2018 [34]*
Hymenobacter actinosclerus, Chryseobacterium chaponense	Carotenoid bacterial pigments	PCR, UV-vis spectrophotometry, FTIR spectroscopy	0.0332% 0.0323%	0.2 0.13	435 mV 548.8 mV	Órdenes-Aenishanslins N *etal, 2016 [15]*
Amaranthus tricolour L	Chlorophyll	UV-vis spectrophotometry, FTIR spectroscopy,	0.53%.	1.3	0.582	R Ramanarayanan *etal, 2017 [17]*

		Electrochemical impedance spectroscopy. Bode plot. Solar simulator.				
Malva verticillata, *Enteromorpha,* *Suaeda aegyptiaca,* *Sargassum,* *Garcilaria*	Chlorophyll Flavonoid Fucoxanthin phycoerythrin	UV-vis spectroscopy, Circular dichroism spectroscopy, Dynamic light scattering spectroscopy, Cyclic voltametry, Atomic force microscopy.	1.702% 1.054% 1.168% 0.731% 0.760%	1.417 1.110 1.151 0.943 0.879	0.542 0.473 0.491 0.404 0.442	Malihe Golshan *et al,* 2019 [18]
Streptomyces fildesensis	Bacterial pigment (melanin family)	UV-vis spectrophotometry, FTIR spectroscopy,	0.026%	0.091	493	C Silva *etal, 2019 [20]*
Serratia marcescens 11E	prodigiosin	HPLC, UV-vis spectrophotometry, FTIR and NMR spectroscopy, Bipotentiostat, Electrochemical impedance spectroscopy.	0.032%	0.096	560 mV	Patricia Hernández-Velasco *et al*, 2020 [21]
Cordyline fruticosa, *Hylocereus polyrhizus*	Chlorophyll, Anthocyanin, Betalains	UV-vis spectrophotometry, FTIR spectroscopy, X ray diffraction analysis, Energy dispersive X-ray spectroscopy	0.5% 0.16%	1.3 0.4	0.62 0.5	Mahmoud A.M.Al-Alwani *etal, 2017 [22]*
Blackberry, *blueberry,* *cherry,* *raspberry,* *strawberry*	Anthocyanin	HPLC, UV-vis spectrophotometry, Solar simulator, Source meter, monochromator,	0.21% 1.13% 0.21% 0.20% 0.14%			F. Teoli *etal, 2016 [23]*
Red seaweed	Phycoerythrin	UV-vis spectrophotometry, FTIR spectroscopy,Electrochemical impedance spectroscopy. Total organic carbon analyzer coupled with chemiluminescence detector, Galvanostat, solar simulator,	0.52%	1.26	0.66	A Rapsomanikis *etal, 2016 [44]*

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IV. ABSORPTION SPECTRUM of VARIOUS DYES

The absorption characteristics of a dye extracted from a source is studied using a spectroscopic technique that involves inducing light on the cell to carry out spectroscopic analysis. Such analyses give crucial information about the kinetics of the cell and shows which dyes introduce electrons into the semi-conductor layer of TiO_2, ZnO or SnO_2 and those that do not [38]. This is usually obtained by the use of a UV-Vis spectroscope and it gives detailed data on the absorption peaks obtained at specific wavelengths of incident light, thereby giving the nature and type of pigment present. Values of the wavelengths obtained at the peaks obtained can then be used to formulate the concentration of the pigments present in the source from which it is extricated [2] Some of the frequently used pigments and its absorption spectrum data are given below (Table 3).

PIGMENT	SOURCE	ABSORPTION SPECTRUM OF PIGMENTS (NM)	REFERENCES
Chlorophyll	*Undaria pinnatifida*	400-430 600-650	Giuseppe Calogero *etal, 2013 [24]*
Phycocyanin phycoerythrin chlorophyll	*Iridaea obovata Delesserialancifolia Plocamium hookeri*	540 and 620 430-662 450-500	Paula Enciso and María Fernanda Cerdá, 2016 [2]
MFK dye HSF dye	*Murraya koenigii* *Hibiscus sabdariffa*	538 539	S. Rajkumar, *etal, 2019 [19]*
Chlorophyll Betalain	*Amaranthus cruentus*	660 536	Rajita Ramanarayanan, *etal, 2017 [17]*
Chlorophyll	*Scenedesmus obliquus*	666	A. Orona-Navar, *etal, 2020 [33]*
Carotenoid anthocayanin	*Tecomaria capensis,* *Kalanchoe,* *Bauhinia*	495 512 527	Giphin George, *etal, 2020 [35]*
Dye	*Acalypha godseffiana Epipremnum aureum*	250-290 250-700	Nallamuthu Ananthi, *etal, 2019 [36]*
Anthocayanin	*Canna lily red* *Canna lily yellow*	500	Suprabha Sahoo, *etal, 2020 [37]*

Table III: Absorption spectrum of various dyes

V. APPLICATIONS

Natural pigments can be used as promising sensitizers in DSSCs to replace the metal complexes or organic dyes. They are eco-friendly, low cost, simple extraction procedure and widely available compared to the metal complexes or organic dyes. Simple modifications and further refining purification of the existing natural pigments can easily be done by applying new techniques in the DSSC fabrication process and that could open up new research areas to improve the efficiency and stability of the device. In considering the cost of dyes used in DSSCs, natural dyes have a negligible cost as compared to the costs of the other available dyes. Natural pigments based DSSCs would be a good candidate for the sustainable solution for future energy issue [12]. Even though natural dye based solar cells have lower light to electricity conversion efficiency when compared with cells employing synthetic dyes, natural dyes are relatively cheaper, environmentally friendly, non-toxic, and are easily available. Thus, low conversion efficiencies of these natural sensitizers can boost research interest and provide opportunities to explore new natural dyes rendering good stability and higher efficiencies [13].

To improve light harvesting and charge separation, DSSC allows independent selection of light absorbing and charge transport materials. Organic materials also provide benefits such as cost effectiveness, ease of processing and synthesizing, flexibility and the ability to bend, the ability to be deposited on a flexible substrate, the ability to be selected based on absorption requirements, and are environmentally benign substances [41]. Nanoparticles boost dye absorption on semiconductors even further.

Vegetable dyes based DSSC have a lower efficiency but they could be used in some niche applications, e.g., indoor applications (diffuse light) for powering small systems and home appliances, battery chargers for portable devices or educational demonstrators, where they can in principle compete with silicon-based solar cells. The study of natural dyes remains an attractive and challenging goal contributing to a solution for future alternative environmentally sustainable energy conversion [14].

VI. PATENTS OF DYE SENSITIZED SOLAR CELLS

With a rapidly growing number of scientific articles and patent filings, dye-sensitized solar cell technology has evolved into a major field of study and development. After the turn of the century, DSSC patent activity exploded with Asia accounting for the vast bulk of DSSC patent applications. Japan, China, and Korea account for over 90% of the research patents in the database.

Over 75% of the patent applications are regarding the materials in the assembly of a DSSC, primarily semiconductor materials, electrolytes and dyes [31].

Table IV: Recent patents on Dye Sensitized Solar Cells

TITLE	PATENT ID	INVENTOR	PUBLISHED
Dye-sensitized solar cells and solar cell modules	JP2021057495A	Yohiro Kojima and co-workers	08-04-2021
Dye-sensitized solar cell	TW202021144A	Zhou Rongquan and co-workers	01-06-2020
Low-temperature and low-pressure preparation method of flexible dye-sensitized solar cell	CN105551834B	Xiong Yan and co-workers	03-05-2017
Genetic recombined phycocyanobilin serving as optical sensitization material and application thereof	CN105742069A	Ge Baosheng and co-workers	06-07-2016
Anthocyanin modification method for dye-sensitized solar cell	CN108806991B	Yang Guijun and co-workers	07-01-2020
Application of phthalocyanine from cashew nut (lcc) shell liquid to sensitized solar cell	BR102016030264A2	Selma Elaine Mazzetto and co-workers	30-10-2018
The preparation method of DSSC	CN107658136A	Yao Chenzhong and co-workers	02-02-2018
Organic dye for a dye-sensitized solar cell	WO2013160201A1	Paolo Biagini and co-workers	31-10-2013

VII. CONCLUSION

The photovoltaic industry is presently dominated by inorganic p-n junction devices usually built of silicon, owing to their high photon-to-current efficiency. The development of DSSCs, however, is standing up to the supremacy of these p-n junction devices because of their low manufacturing cost, environmental-friendliness and easy availability of the natural dyes as an alternative source to the harmful chemicals. Natural dyes that absorb sunlight throughout the visible spectrum with greater efficiency have been used in recent advancements on several types of sensitizers for DSSC devices. The major element determining the DSSC effectiveness is the type of the dye employed as sensitizers. Chlorophyll C as a photosensitizer has shown significant efficiency values of up to 4% and some DSSCs have shown even higher values of 9%. This review mentions values of efficiencies: Phycobiliproteins (up to 1%), chlorophyll c1 (up to 3.5%), chlorophyll c2 (up to 4.6%), carotenoid bacterial pigments (up to 0.04%), phycobiliproteins (up to 1%). The data presented in this review shows a significant promise for further research in using natural dyes as photo-sensitizers to increase the efficiencies to match that of the traditional inorganic photo-voltaic devices. Therefore, the use of uncommon sources such as microalgae and microalgae in the renewable energy source sector could boost the utilization of algae to increase the feasibility of the natural DSSCs and make the natural DSSCs a better substitute to the inorganic solar cells.

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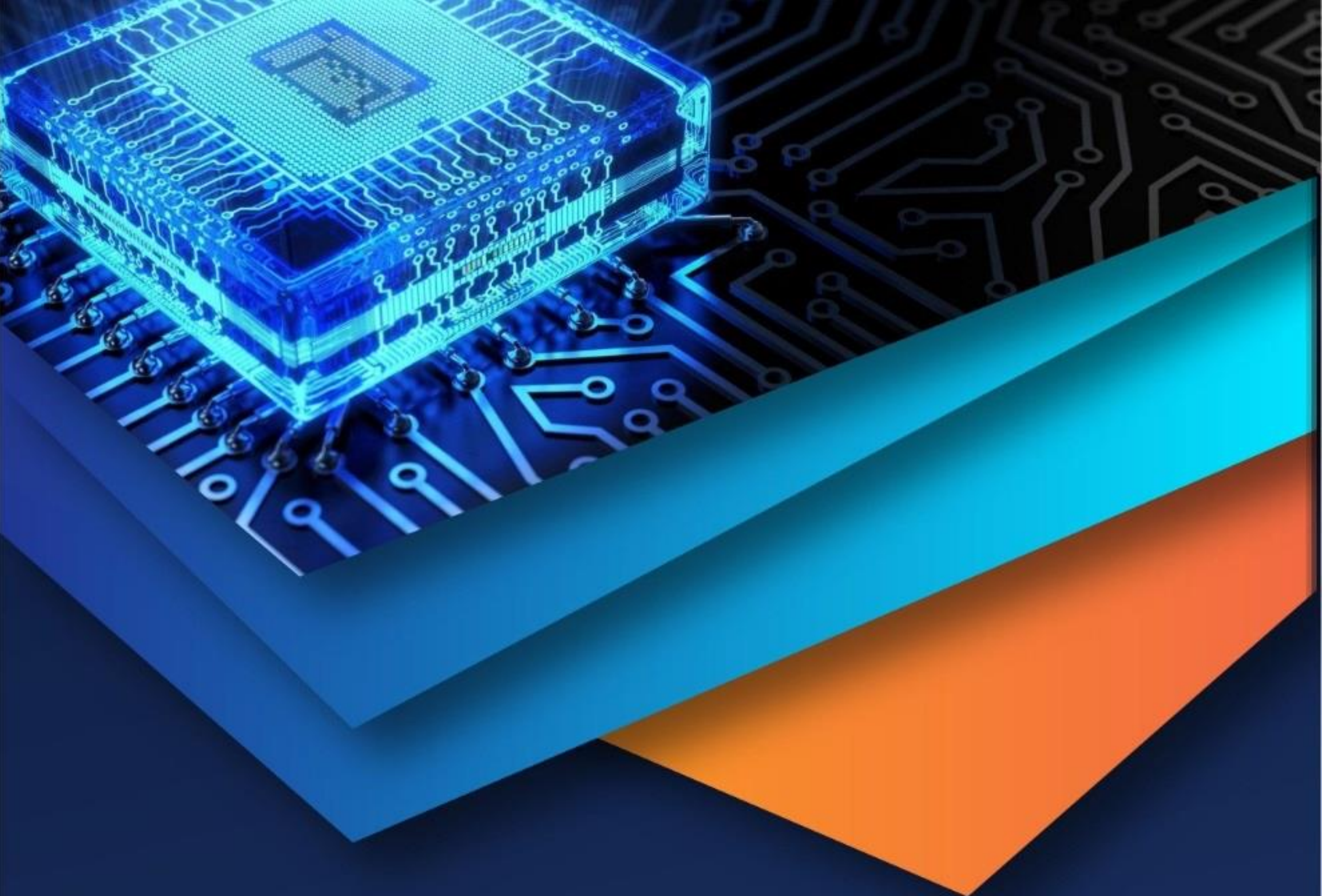

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