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Dye Sensitized Solar Cell Based On A New Class Of Doubly Concerted Companion Dyes

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ABSTRACT: Dye-sensitized solar cells (DSSCs) belong to the group of thin-film solar cells which have been under extensive research for more than two decades due to their low cost, simple preparation methodology, low toxicity and ease of production. Still, there is lot of scope for the replacement of current DSSC materials due to their high cost, less abundance, and long-term stability. The efficiency of existing DSSCs reaches up to 12%, using Ru(II) dyes by optimizing material and structural properties which is still less than the efficiency offered by first- and second-generation solar cells, i.e., other thin-film solar cells and Si-based solar cells which offer ~20–30% efficiency. This article provides an in-depth review on DSSC construction, operating principle, key problems (low efficiency, low scalability, and low stability), prospective efficient materials, and finally a brief insight to commercialization.

KEYWORDS: dye sensitized, solar cell, doubly concerted, companion dyes, commercialization

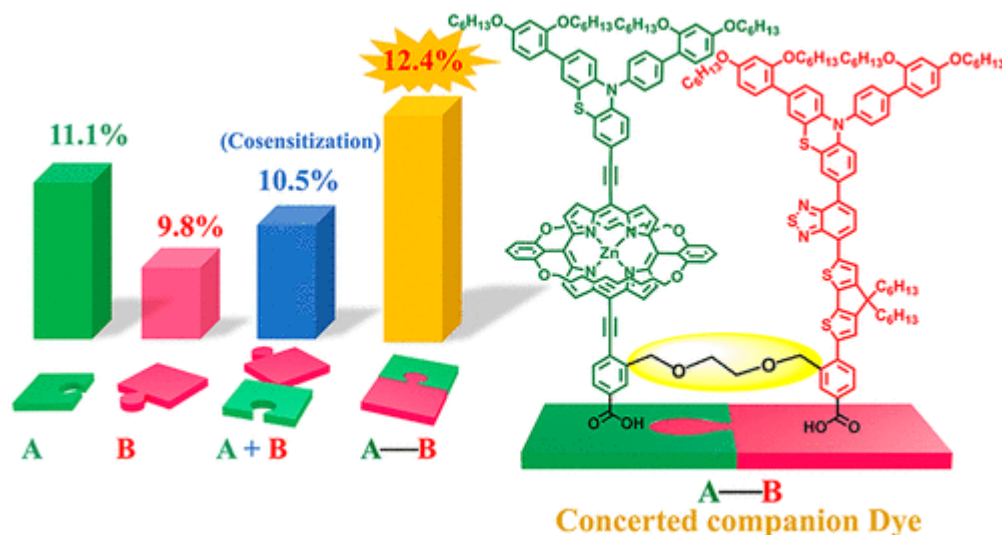
I. INTRODUCTION

With the purpose to achieve panchromatic absorption for constructing efficient dye-sensitized solar cells (DSSCs), the cosensitization approach of using two dyes with complementary absorption has been developed with great success. However, this approach usually requires time-consuming optimization of a number of parameters for controlling the ratio and distribution of the two coadsorbed dyes on TiO₂ film, which limits the potentials of this strategy. We herein report an alternative approach for developing efficient DSSCs by designing a class of “concerted companion dyes” with two complementary dye components linked covalently. Thus, a newly synthesized organic dye Z2 was linked to a recently reported doubly strapped porphyrin dye XW51 through flexible chains with various lengths to afford XW60–XW63. These dyes exhibit excellent absorption and efficiencies in the range of 8.8%–11.7%. Notably, upon coadsorption with chenodeoxycholic acid, XW61 affords an impressive efficiency of 12.4%, a record for iodine electrolyte-based DSSCs, to the best of our knowledge. In addition, these dyes also exhibit the advantages of easy cell fabrication, simple optimization, as well as excellent photostability.[1,2]



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Among the third-generation photovoltaic devices, dye-sensitized solar cells (DSSCs) have aroused considerable attention owing to their easy fabrication and colorful appearance since the first report by Grätzel and O'Regan in 1991 [1-3]. The power conversion efficiencies (PCE) have been dramatically promoted with the development of various mesoscopic semiconductors [4], photosensitizers [5], redox shuttles [6, 7] and device designs [8, 9]. Among them, the photoactive sensitizers act as the electron pumps to harvest light and transfer the excited electrons into the semiconductor in the DSSCs. In this respect, various types of sensitizers have been developed. For example, ruthenium-based complexes [10], metal-free organic dyes [11-13] and zinc porphyrin dyes [14-18] have been designed to enhance the PCEs [19-20].

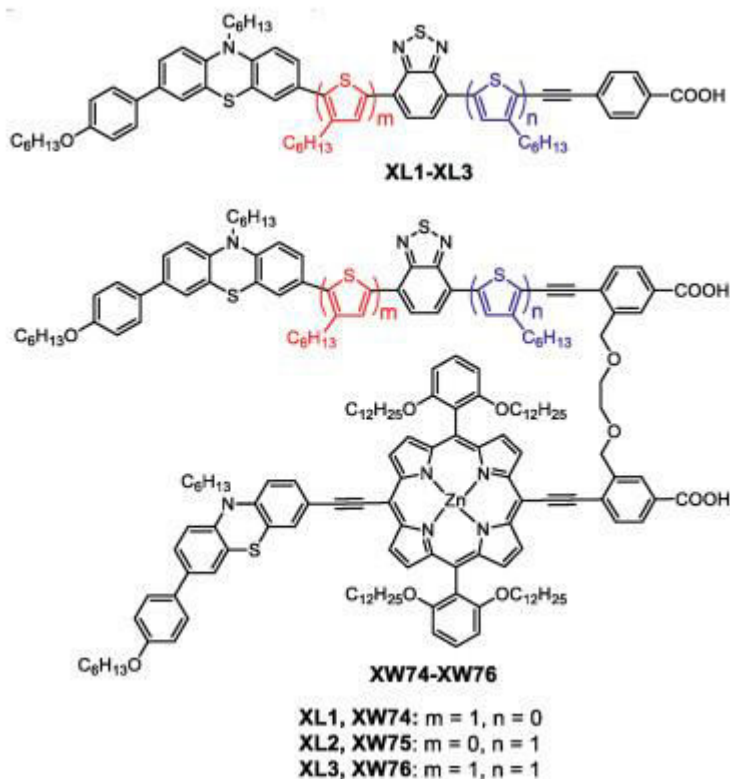
Porphyrin sensitizers, as the analogues of chlorophylls in photosynthesis, possess the properties of intense and broad absorption, convenient modification and remarkable light-thermal stability, which enable them to be effective in fabricating efficient DSSCs [11]. However, the absorption valley for porphyrins in the green light region limits their light-harvesting capability and the related photovoltaic performance [13].

To fill up the absorption valley and improve the PCEs, various organic sensitizers have been designed and used as the cosensitizers for porphyrins to fabricate efficient DSSCs [14]. However, a number of factors need to be optimized for fabricating the cosensitized DSSC devices, and the distribution of the dyes on the semiconductor is rather difficult to control, which is unfavorable for further improving the photovoltaic performance [16]. To address these problems, we have recently developed a novel class of concerted companion (CC) dyes to achieve the "intramolecular cosensitization" effect by covalently linking the organic dye and porphyrin dye units through long chains [18]. Remarkably, such dyes feature panchromatic absorption, and endow the corresponding DSSCs with high-efficiency and long-term photostability. Based on this background, we herein report the optimization of the organic dyes to systematically modulate the absorption and thus improve the performance of CC dyes. With respect to the design of organic dyes, the thiophene unit has been extensively used as the π spacer [20], and its number [10] and position [8] in the dye framework dramatically affect the photophysical properties of the sensitizers. Thus, three organic dyes XL1-XL3 have been synthesized by incorporating the β -hexylthiophene (HT) unit as the π spacer, the electron-rich phenothiazine unit as the donor [38, 39], and benzothiadiazole as the auxiliary acceptor [6]. Then, these organic dye units are covalently linked with our previously reported porphyrin dye XW10 [20] to construct the corresponding CC dyes XW74-XW76



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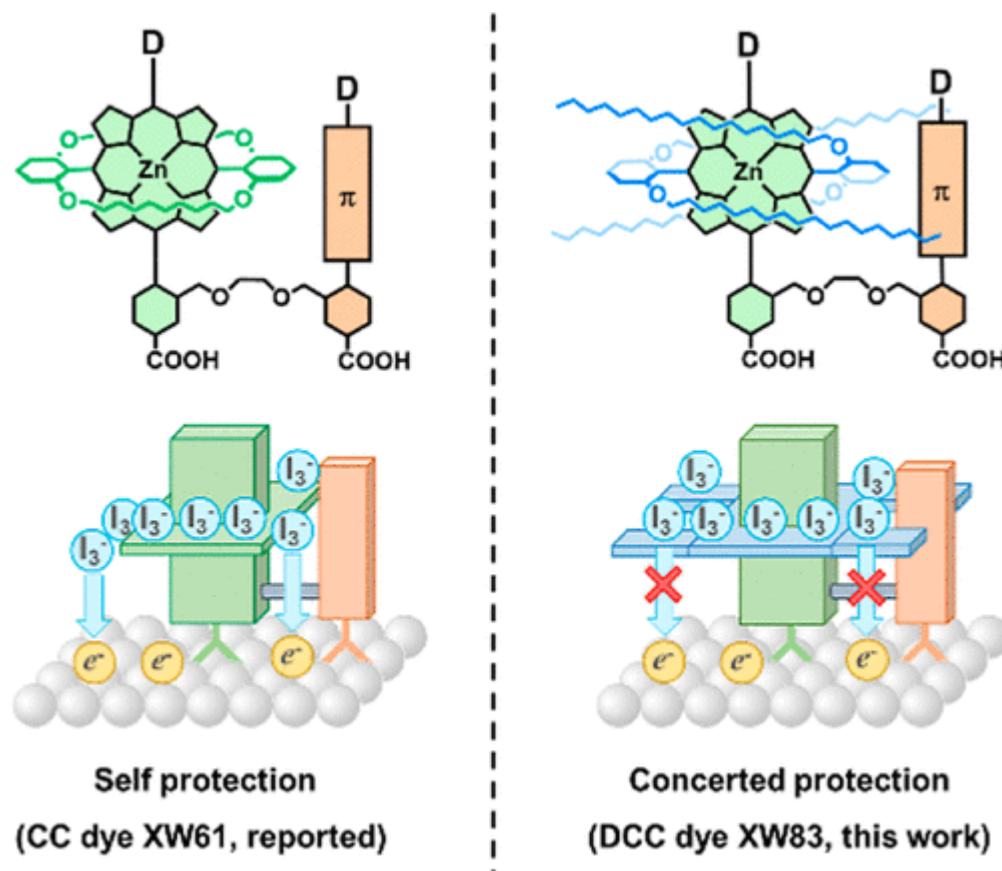
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Molecular structures of dyes XL1-XL3, XW74-XW76.

II. DISCUSSION

To develop efficient dye-sensitized solar cells (DSSCs), concerted companion (CC) dyes XW60–XW63 constructed from the covalent linkage of a strapped porphyrin dye unit and an organic dye unit have been reported to exhibit panchromatic absorption and excellent photovoltaic performance. However, these CC dyes only afforded moderate VOC values of ca. 763 mV, demonstrating relatively weak antiaggregation ability, which remains an obstacle for further enhancing the photovoltaic behavior. To address this problem, we herein develop porphyrin dyes XW77–XW80 with the macrocycles wrapped with alkoxy chains of various lengths (OC6H13–OC22H45) and the corresponding CC dyes XW81–XW84 containing these porphyrin dye units. Interestingly, the new CC dyes XW81–XW83 exhibit increasing VOC from 745 to 784 mV with the chain lengths extended from C6 to C18, and a lowered VOC of 762 mV was obtained for XW84 when the chain length was further extended to C22.[3,4] As a result, XW83 afforded the highest PCE of 12.2%, which is, to the best of our knowledge, the record efficiency for the iodine electrolyte-based solar cells sensitized with a single dye. These results can be rationalized by the so-called doubly concerted companion (DCC) effects, that is, the two subdye units exhibit not only complementary absorption but also concerted antiaggregation with the long wrapping chains on the porphyrins unit simultaneously protecting the porphyrin macrocycle and the neighboring organic subdye unit, thus affording panchromatic absorption and strong antiaggregation and anticharge-recombination ability. [5,6] These results provide a new approach for constructing a class of DCC dyes to achieve high-performance DSSCs without using any antiaggregating coadsorbent or absorption-enhancing cosensitizer.[7,8]



Construction of di-anchoring organic sensitizers has been recently recognized as an effective strategy to develop high-efficiency dye-sensitized solar cells (DSSCs). However, the relatively low open-circuit photovoltage (V_{oc}) for di-anchoring dyes have become to be the bottle-neck for further advancing the photovoltaic performance. In this work, two novel L(D- π -A)₂ type di-anchoring sensitizers, W11–W12, featuring 9H-thieno[2',3':4,5]thieno[3,2-b]thieno[2',3':4,5]thieno[2,3-d]pyrrole (TTTP) as π -conjugated spacer, have been developed and well examined for a systematical study of the structure-property relationship of these dyes. Through the rational adjustment of donor-linking bridges, carbazole decorated W12 exhibits dramatically enhanced light-harvesting efficiency as well as self-anti-aggregation ability with respect to those of W11 employing triphenylamine linkage. More importantly, a compact arranged organic layer benefiting from the superior dye-loading amounts has been formed for W12,[9,10] which is beneficial to keep the oxidized electrolyte from the TiO₂ surface, thus bringing forth more efficient suppression of interfacial charge recombination and consequently higher V_{oc} values. Under standard AM 1.5 G illumination, DSSCs sensitized by W12 employing [Co(phen)₃]^{2+/3+} electrolyte display a fascinating power conversion efficiency as high as 8.28%, with an impressive open-circuit voltage (V_{oc}) of 847 mV, which is among the highest cells efficiencies of L(D- π -A)₂ type di-anchoring organic dyes.[11,12]

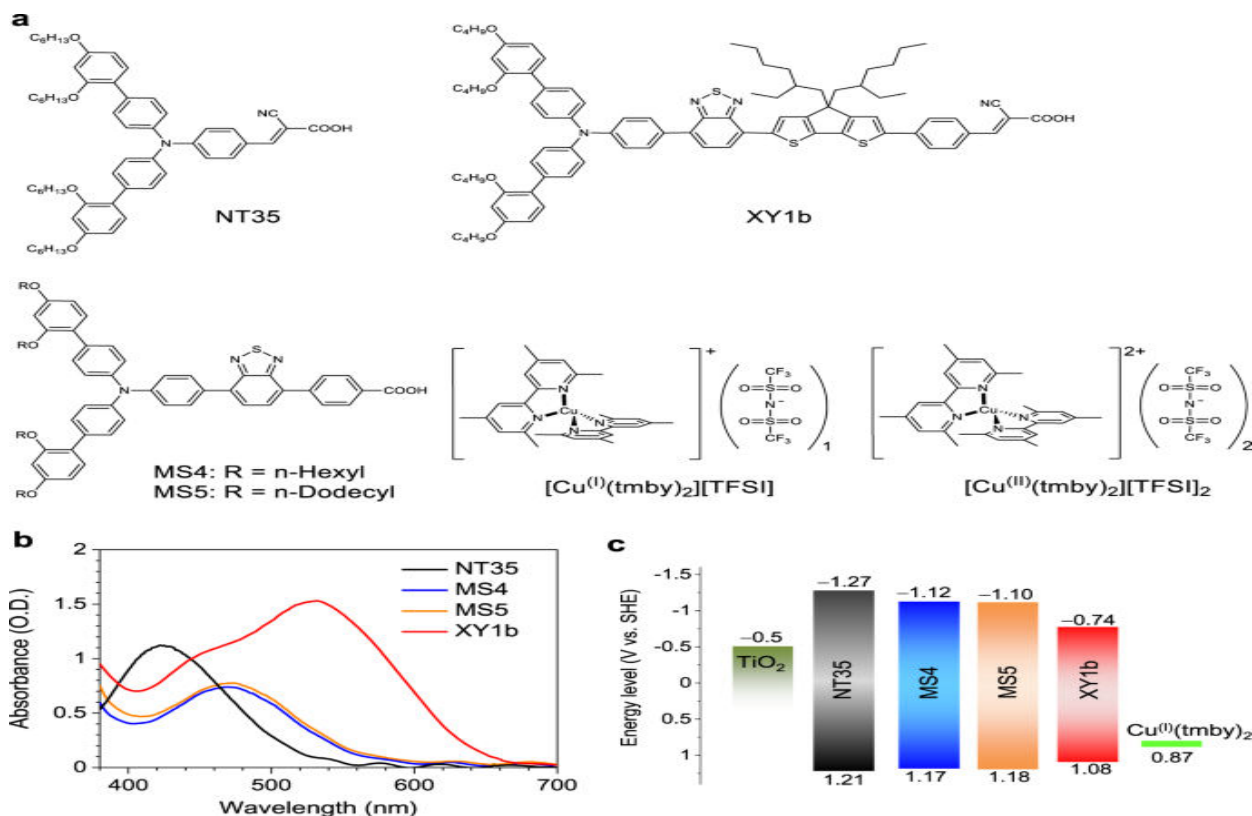
Organic concerted companion (CC) dyes CCOD-1 and CCOD-2 were constructed by covalently linking two organic dye units with complementary absorption spectra. Both CC dyes exhibited intense absorption from 300 to 650 nm with the band edges extended to 700 nm. These CC dyes were used to fabricate dye-sensitized solar cells (DSSCs), and the photovoltaic performance was investigated using different light sources. CCOD-2 possessed bulkier outer shelter than CCOD-1 owing to the longer carbon chains (C₁₂) at the donor moiety, and thus it had stronger anti-aggregation and anti-charge-recombination ability. Under simulated sunlight (AM1.5G), CCOD-2 exhibited enhanced photovoltaic behavior with an open-circuit voltage (V_{oc}) of 759 mV, short-circuit current density (J_{sc}) of



19.23 mA · cm⁻², and power conversion efficiency (PCE) of 10.4 %, respectively. Notably, under the illumination of the indoor T5 fluorescent lamp (2500 lux), CCOD-2 afforded an enhanced PCE of 28.0 % with remarkable V_{OC} and J_{SC} of 692 mV and 0.424 mA cm⁻², respectively. Notably, the PCE achieved for CCOD-2 outperformed those of the reference sensitizer N719 and our previously reported CC dyes XW61 and XW70-C8 under the same indoor lamp conditions. In summary, the novel organic CC dyes developed in this work were demonstrated to be promising for fabricating DSSCs to efficiently harvest the energy of indoor lamps.[13,14]

III. RESULTS

To develop photosensitizers with high open-circuit photovoltage (V_{oc}) is a crucial strategy to enhance the power conversion efficiency (PCE) of co-sensitized solar cells. Here, we show a judiciously tailored organic photosensitizer, coded MS5, featuring the bulky donor N-(2',4'-bis(dodecyloxy)-[1,1'-biphenyl]-4-yl)-2',4'-bis(dodecyloxy)-N-phenyl-[1,1'-biphenyl]-4-amine and the electron acceptor 4-(benzo[c][1,2,5]thiadiazol-4-yl)benzoic acid. Employing MS5 with a copper (II/I) electrolyte enables a dye-sensitized solar cell (DSC) to achieve a strikingly high V_{oc} of 1.24 V, with the V_{oc} deficit as low as 130 mV and an ideality factor of merely 1.08. The co-sensitization of MS5 with the wider spectral-response dye XY1b produces a highly efficient and stable DSC with the PCE of 13.5% under standard AM1.5 G, 100 mW cm⁻² solar radiation. Remarkably, the co-sensitized solar cell (active area of 2.8 cm²) presents a record PCE of 34.5% under ambient light, rendering it very attractive as an ambient light harvesting energy source for low power electronics. Since the industrial revolution, tremendous consumption of fossil fuels has led to rapid growth of the global economy and improved quality of life, but at the cost of high risks and impacts of climate change due to the CO₂ emission. The Paris agreement, which aims to hold the increase in the global average temperature to well below 2 °C above pre-industrial levels, relies on the development of renewable energy technologies to reduce the consumption of fossil fuels. Photovoltaics (PV) now supply nearly 3% of global electricity reducing CO₂ emission and attenuating climate change. Thus, Germany's PV generated 47.5 TWh electric energy in 2019, covering 8.2% of the country's gross electricity demand in the same year and avoiding about 29 million tons of CO₂ emission[15,16]



IV. CONCLUSIONS

The use of existing fossil fuels for energy needs is accepted as the main cause of global climate change. Silicon solar cells or organic solar cell which are an alternative solution to this traditional fossil energy and can directly converts solar energy to electrical energy, have become the focus of attention [1- 5]. The limited performance and high production costs of inorganic silicon-based solar cells used today have increased the search for alternative materials to these cells [6]. DSSC technology is an alternative to silicon-based solar cells technology [7-9]. The DSSC is constituted of three main parts. These layers can be listed as the two conductive contacts, the redox layer and the dye material that consisting of organic semiconductor material located between these contacts [8-11]. In this point organic semiconductor materials play an important role in layer of the DSSC device [12-15]. One of the layers that the molecular structure of the organic semiconductor dye material can be designed to consist of donor and acceptor parts [16-18]. Thus, this design let to be transferring the electrons easily in the device. In order for all molecular electronic technology devices to work efficiently, the electron transfer in organic semiconductor dye between the electron donor (donor) and electron acceptor (acceptor) parts must take place effectively [17,18]. Donor-Acceptor type organic semiconductor materials (small molecules) are of great interest, especially since they are systems in which energy and electron transfer can be controlled [10]. One of the advantages of these materials is that the p-doping and n-doping properties of the material are determined by controlling the energy of the conjugated π system with the regular repetition of donor and acceptor monomers in the chain, and the HOMO-LUMO band gap can be easily tuned [19]. Because of these properties, it is common to use the donor-acceptor type materials in molecular electronics, nonlinear optical materials, and optoelectronic technology devices. Donor-Acceptor type small molecules are widely used in organic electronics, especially since they are systems in which energy and electron transfer can be controlled. One of the advantages of these materials is that the p-doping and n-doping properties of the material are determined by controlling the energy of the conjugated π system with the regular repetition of donor and acceptor monomers in the chain, and the HOMOLUMO band gap can be easily tuned. Because of these



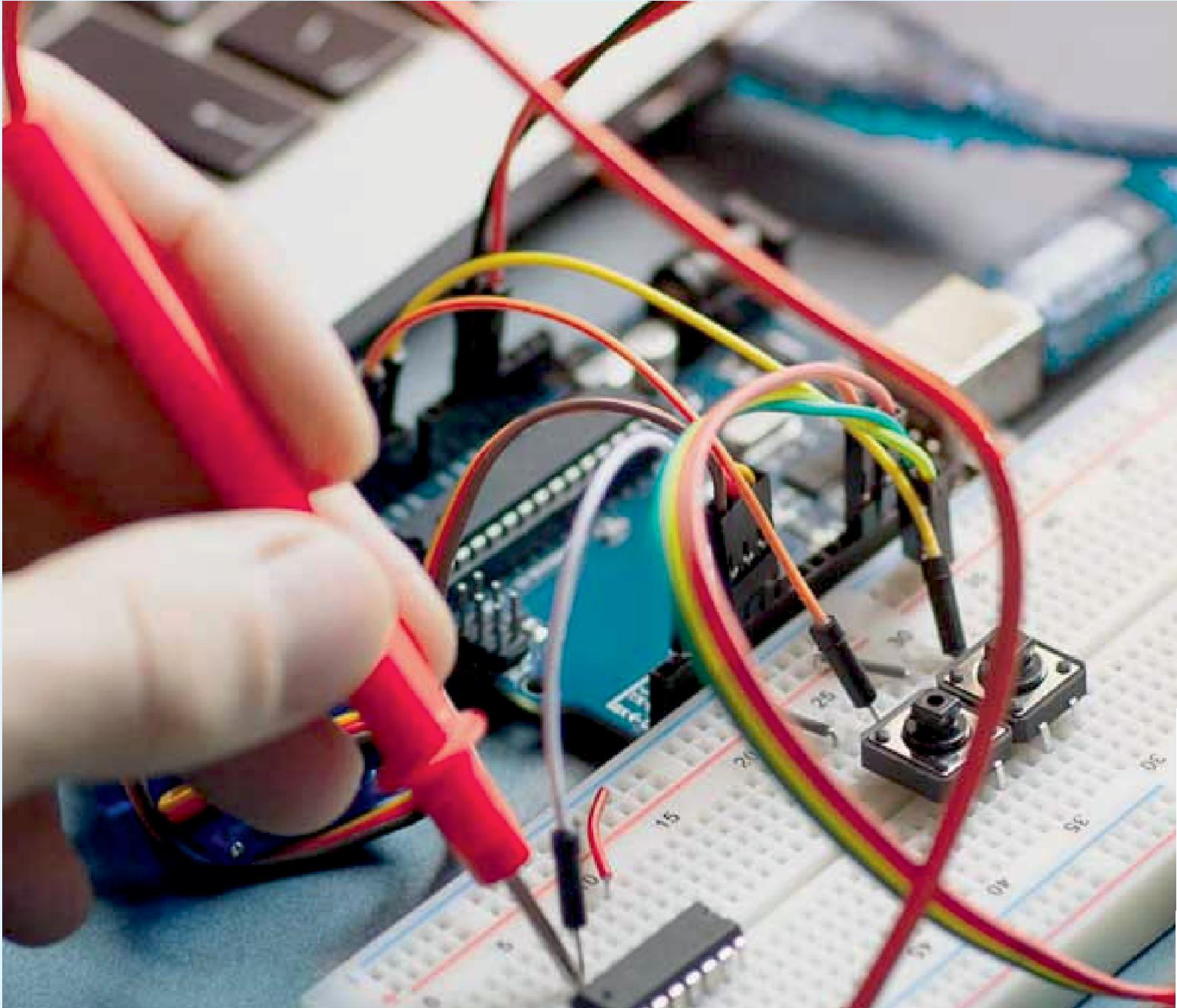
properties, the use of donor-acceptor type materials in molecular electronics, nonlinear optical materials, and optoelectronic technology devices is common [19]. Organic semiconductor materials-based solar cells continue to be studied intensively due to their low production cost, their ability to cover large surfaces, their mechanical flexibility, and their constantly increasing efficiency. In addition, since organic solar cells can be produced in transparent form, it offers the opportunity to use this technology in all areas of daily life such as automotive and construction glass.[20]

REFERENCES

1. Om Prakash and SK Yadav, Study of Photogalvanic Effect by Using of Natural Dye as Photosensitizer for Solar Energy Conversion and Storage, *Cent. Asia. J. Theo. App. Scie.*, 03(07), 78-83,2022.
2. Om Prakash A Sonel and SK Yadav, Conversion of Solar Radiation into Electrical Energy by Using Solar Cell, *Cent. Asia. J. Theo. App. Scie.*, 03(07), 104-107,2022.
3. SK Yadav and S Sharma, Use of Azur-C-NTA as a new sensitizer-Reductant system for enhanced simultaneous solar power conversion and storage by Photogalvanic cell, *Int. J. Res. Bio. Agri. Tech.* 17, 245- 252, 2021.
4. SK Yadav, Solar energy conversion and storage by using Rose extract as Natural Dye and NTA as reductant in PG Cell, *AIP Conference Proceeding*,1953,080033, 2018, <https://doi.org/10.1063/1.5032839>
5. SK Yadav, Advance environment successive key for solar energy conversion and storage using Thionine-Glucose- CTAB in Photogalvanic cell system, *Int. J. Civ. Eng.*, 3 (5), 16-21 2016.
6. SK Yadav, G Singh and RD Yadav, Photogalvanic Solar Conversion and Storage by using Thionine as Photosensitizer and EDTA as Reductant in the presence of CTAB as Surfactant, *Afinidad*, LXVII, 550, 473-477, 2010. <https://www.raco.cat/index.php/afinidad/article/view/269642>
7. S Yadav, RD Yadav and G Singh, Use of Dyes in Photogalvanic cell for Solar Energy Conversion and Storage: Bismarck Brown and Ascorbic Acid System, *Int. J. Chem. Sci.*, 6(4), 1960-1966, 2008.
8. Gong J, Sumathy K, Qiao Q, Zhou Z (2017) Review on dye-sensitized solar cells (DSSCs): Advanced techniques and research trends. *Renewable and Sustainable Energy Reviews* 68: 234-246.
9. Semalti P, Sharma SN (2020) Dye sensitized solar cells (DSSCs) electrolytes and natural photo-sensitizers: A review. *J Nanosci Nanotechnol* 20: 3647-3658.
10. Karim NA, Mehmood U, Zahid HF, Asif T (2019) Nanostructured photoanode and counter electrode materials for efficient Dye-Sensitized Solar Cells (DSSCs). *Solar Energy* 185: 165-188.
11. Kumar R, Sahajwalla V, Bhargava P (2019) Fabrication of a counter electrode for dye-sensitized solar cells (DSSCs) using a carbon material produced with the organic ligand 2-methyl-8-hydroxyquinolinol (Mq). *Nanoscale Adv* 1: 3192-3199.
12. Haque SA, Park T, Xu C, Koops S, Schulte N, et al. (2004) Interface engineering for solid-state dyesensitized nanocrystalline solar cells: The use of ion-solvating hole-transporting polymers. *Advanced Functional Materials* 14: 435-440.
13. Cavallo C, Di Pascasio F, Latini A, Bonomo M, Dini D (2017) Nanostructured semiconductor materials for dye-sensitized solar cells. *Journal of Nanomaterials* 2017.
14. Agarwala P, Kabra D (2017) A review on triphenylamine (TPA) based organic hole transport materials (HTMs) for dye sensitized solar cells (DSSCs) and perovskite solar cells (PSCs): Evolution and molecular engineering. *J Mater Chem A* 5: 1348- 1373.
15. Ammar AM, Mohamed HS, Yousef MM, AbdelHafez GM, Hassanien AS, et al. (2019) Dye-sensitized solar cells (DSSCs) based on extracted natural dyes. *Journal of Nanomaterials* 2019.
16. Heredia D, Natera J, Gervaldo M, Otero L, Fungo F, et al. (2010) Spirobifluorene-bridged donor/acceptor dye for organic dye-sensitized solar cells. *Org Lett* 12: 12-15.
17. Click KA, Beauchamp DR, Garrett BR, Huang Z, Hadad CM, et al. (2014) A double-acceptor as a superior organic dye design for p-type DSSCs: high photocurrents and the observed light soaking effect. *Physical Chemistry Chemical Physics* 16: 26103- 26111.
18. El-Shishtawy RM, Asiri AM, Aziz SG, Elroby SAK (2014) Molecular design of donor-acceptor dyes for efficient dye-sensitized solar cells I: a DFT study. *J Mol Model* 20: 2241.
19. Zhang J, Kan Y-H, Li H-B, Geng Y, Wu Y, et al. (2012) How to design proper π -spacer order of the D- π -A dyes for DSSCs? A density functional response. *Dyes and Pigments* 95: 313-321.



20.Kim BG, Chung K, Kim J (2013) Molecular design principle of all-organic dyes for dye-sensitized solar cells. Chemistry 22: 5220-5230.



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