Bachelor of Engineering in Electronics and Instrumentation Engineering

2022-2023

R V College of Engineering®, Bengaluru

(Autonomous institution affiliated to VTU, Belagavi)

EXPERIENTIAL LEARNING REPORT

LOW-TEMPERATURE FABRICATION OF DYE-SENSITIZED SOLAR CELL.

(WITH COMPOSITE LAYERS)

R.V. COLLEGE OF ENGINEERING

(An Autonomous Institution under VTU, Belagavi)

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Course Outcomes	CO1	CO2	CO3	CO4
CO Attainment in marks				

Certificate

This is to certify that **Kushal Mandhyan, Sandeep N Uttarkar, Shikhar Verma, Shubham R** of II Semester **Electronics and Instrumentation Engineering** Branch has satisfactorily completed the **Assignment/Seminar presentation** prescribed by the Institution in the Chemistry of Functional Materials; Vector Calculus, Laplace Transform and Numerical Methods course for the academic year 2022-23.

Title of Topic: Low-Temperature Fabrication of Dye-Sensitized Solar Cell.

Max. Marks	Marks Obtained
20	

Name of the Student **Signature of the Faculty** **Signature of H.O.D.**

1. Kushal Mandhyan
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3. Shikhar Verma
4. Shubham R

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INTRODUCTION

Energy, according to scientists, is the capacity to work. Modern civilization is only possible because people have learned how to change energy from one form to another and then use it to do work. The process of life on Earth is sustained by a constant supply of energy, primarily from sunlight.

Sources of Energy

Primary energy sources include nuclear energy, fossil energy (such as oil, coal, and natural gas), and renewable energy sources such as wind, sun, geothermal, and hydropower. These primary sources are turned to electricity, a secondary energy source that travels to our homes and businesses via power lines and other transmission equipment.

Nonrenewable energy resources now dominate the market, but as the Earth's population grows, so does interest in renewable energy. The change in demand is being driven by pollution from traditional energy sources. Solar energy, for example, is one of the most promising renewable resources because it is plentiful and emits no greenhouse gases.

Solar Energy and Photovoltaics

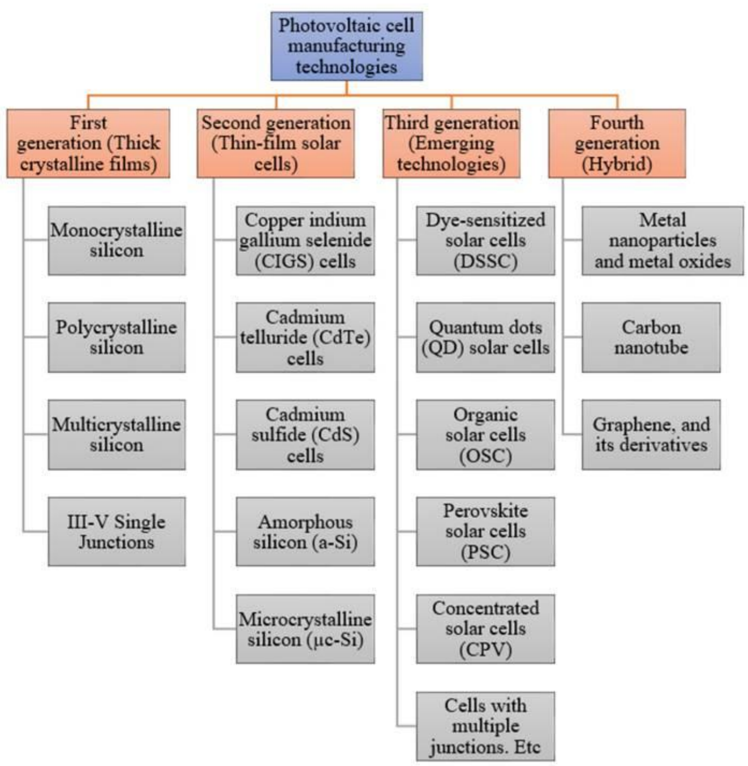
Solar energy, or radiation from the Sun, has the ability to generate heat, cause chemical processes, and generate electricity. The quantity of sunlight that strikes the earth's surface in an hour and a half is enough to power the entire planet for a year. This highly diffused source, if properly harnessed, has the potential to meet all future energy needs.

Solar technologies use photovoltaic (PV) panels or mirrors to concentrate solar radiation to convert sunlight into electrical energy. Photovoltaic (PV) technologies, often known as solar panels, create electricity by absorbing sunlight energy and converting it into electrical energy via semiconducting materials. These operate on the Photovoltaic effect, which refers to the creation of voltage and electric current in a substance in response to light exposure.

Solar Cell Generations

Photovoltaic cells can be categorised into four main generations: first, second, third, and fourth generation.

1. **First Generation:** This category includes photovoltaic cell technologies based on monocrystalline and polycrystalline silicon and gallium arsenide (GaAs).
2. **Second Generation:** This generation includes the development of first-generation photovoltaic cell technology, as well as the development of thin film photovoltaic cell technology from "microcrystalline silicon (μc-Si) and amorphous silicon (a-Si), copper indium gallium selenide (CIGS) and cadmium telluride/cadmium sulphide (CdTe/CdS) photovoltaic cells".
3. **Third Generation:** This generation counts photovoltaic technologies that are based on more recent chemical compounds. In addition, technologies using nanocrystalline "films," quantum dots, dye-sensitized solar cells, solar cells based on organic polymers, etc., also belong to this generation.
4. **Fourth Generation:** This generation includes the low flexibility or low cost of thin film polymers along with the durability of "innovative inorganic nanostructures such as metal oxides and metal nanoparticles or organic-based nanomaterials such as graphene, carbon nanotubes, and graphene derivatives"

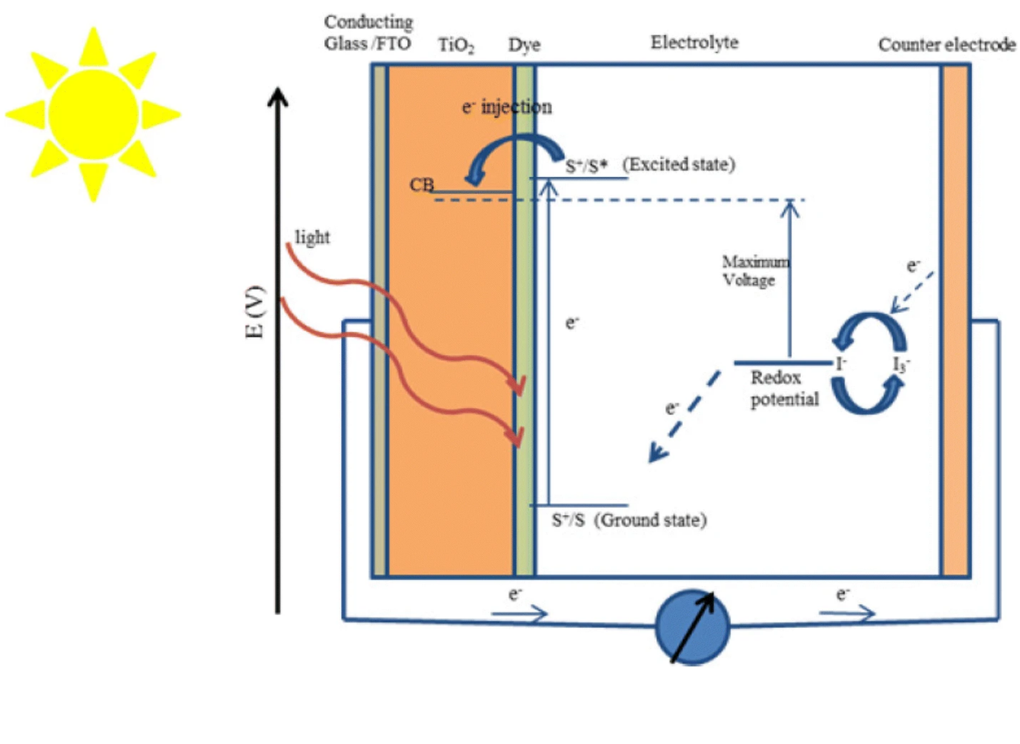


Dye-Sensitized Solar Cells (DSSC)

Dye-sensitized solar cells (DSSCs) were first invented in 1991 by Gratzel and coworkers. The environmental friendliness, cost-efficient, and easy fabrication properties of these solar cells have attracted many researchers. Typically, DSSCs consist of four components: the photoanode consisting of a wide-bandgap semiconductor, the sensitizer acting as a light harvester, the electrolyte containing the redox couple for dye regeneration, and the counter electrode. Although many materials have been used in DSSCs until today, the most used traditional components are TiO2 photoanode, N719 ruthenium-based metal complex dye, I3−/I− redox mediator, and Pt counter electrode. Solar cell efficiency of about 14% was obtained with this type of DSSC.

Dye-sensitized solar cells (DSSCs) belong to the group of thin-film solar cells which emulate the role of leaves during photosynthesis. They have been the subject of in-depth research for more than 20 years because of their affordability, simple preparation process, minimal toxicity, and ease of production. The high cost, low abundance, and long-term stability of the current DSSC materials, however, leave a lot of room for their improvement.

Four essential components of a DSSC are the working electrode, sensitizer (dye), redox-mediator (electrolyte), and counter electrode. It is a combination of a working electrode that has been dyed or sensitized and is attached to a counter electrode that has been coated with a thin layer of electrolyte.



Benefits of DSSC

These solar cells have many advantages over their counterparts and are consequently used in low-density applications and portable gadgets.

1. DSSCs have a good depth in their nanostructure and they absorb the photons in sunlight well. The dyes used in the cells are effective in converting the absorbed photons into electrons. Although the effectiveness of DSSCs is less than many of the best thin film cells, the price-to-performance ratio attained through these solar cells is greater than other such cells.
2. The dye-sensitized solar cells are composed of low-cost materials and are inexpensive to manufacture. These solar cells can be printed on any flexible surface.
3. The dye used in dye-sensitized solar cells absorbs scattered sunlight and fluorescent light. DSSCs also function in cloudy weather and low-light conditions without a great deal of impact on efficiency.
4. Dye-sensitized solar cells do not degrade in sunlight over time as do other thin-film cells, making the cells last longer, and requiring less frequent replacements. DSSCs are also mechanically strong because they are made of lightweight materials and do not require special protection from rain or abrasive objects.

LITERATURE SURVEY

1. Dye-Sensitized Solar Cells: Fundamentals and Current Status

Khushboo Sharma, Vinay Sharma, S. S. Sharma

Overview:

- 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
- A highest efficiency of 14.3% was discussed for the DSSC fabricated with Au/GNP as a counter electrode, $Co3+/2+$ as a redox couple, and LEG4 + ADEKA-1 as a sensitizer.
- The idea dye for DSSC should have absorption spectra covering from UV to infrared spectra, should be luminescent, with HOMO far from TiO2 band and LUMO close to surface, higher than TiO2 conduction band.The periphery of the dye should be hydrophobic to enhance the long-term stability of cells
- Redox couple should be able to regenerate the oxidized dye efficiently.. Should have long-term chemical, thermal, and electrochemical stability, non-corrosive with DSSC components, permit fast diffusion of charge carriers, enhance conductivity,Absorption spectra of an electrolyte should not overlap with the absorption spectra of a dye.
- In terms of limitations, stability failure can be characterized in two different classes: (i) limitation towards extrinsic stability and (ii) limitation towards intrinsic stability. Also, a huge amount of loss in energy of oxidized dye takes place during the process of regeneration, due to the energy mismatch between the oxidized dye and an electrolyte
- In terms of their commercial application, a DSSC needs to be sustainable for > 25 years in building-integrated modules to avoid commotion of the building environment for repair or replacement and a lifespan of 5 years is sufficient for portable electronic chargers integrated into apparel and accessories.

2. Short Review: Natural Pigments Photosensitizer for Dye-Sensitized Solar Cell (DSSC)

N. Jamalullail, I. S. Mohamad, M. N. Norizan, N. A. Baharum, N. Mahmed

Overview:

- The DSSC performance absolutely depends on the type of dye sensitizer used. The traditional DSSC used Ruthenium (Ru) complexes as the sensitizer for getting an efficiency of its highest capability.
- An excellent dye sensitizer, the dye must fulfil certain requirements such as: (i) strong dye attached with semiconductor materials, (ii) broad absorption spectrum and (iii) have the ability to inject the electron into semiconductor materials.As dye is the most important part of the cell it should be of good efficiency.
- **Anthocyanin** is a natural pigment that provides color to flowers, fruits and leaves for the plants . It is commonly exhibited in purple-red range color and absorbs light within 450–600 nm range.**Chlorophyll** is a green pigment that can be found in almost all types of plant. This natural pigment usually exists in leaves. Beside anthocyanin and chlorophyll, **betalain** pigments are also one of the most favourable dye sensitizers in DSSC. Betalain has favourable light absorption and has the carboxylic (COOH) functional group that allows it to bind with TiO2.
- Beetroot is also one of the plants that consists of **betalain** pigments. The beetroot dye has shown the highest absorption peak at 540 nm with the electrical performance of Voc=0.66 V, FF=0.20 and energy conversion efficiency of 0.30%.
- The highest energy conversion efficiency achieved was 2.06% from **betalain** pigments extracted from purple wild Sicilian prickly pear dye. This dye exhibits strong binding with TiO2 nanostructures since betalain pigments also have active carboxylic group (COOH).

3. Fabrication of dye sensitized solar cell using TiO2 coated carbon nanotubes

Tae Young Lee, P.S. Alegaonkar, Ji-Beom Yoo

Overview:

- Fabricate a dye sensitized solar cells (DSCs) using TiO2 coated multi-wall carbon nanotubes (TiO2-CNTs). Carbon nanotubes (CNTs) have excellent electrical conductivity and good chemical stability.
- A composite of poly(p-phenylene vinylene) with CNTs in a photovoltaic device showed good quantum efficiency, owing to the formation of a complex interpenetrating network with the polymer chains.
- A mixture of commercially available TiO2 powder and TiO2-CNTs, along with distilled water, polyethylene glycol, and polyethylene oxide, was ground in a mortar to form a dispersed paste. The paste was then spread on conductive glass by sticking adhesive tape on the sides. After drying, the porous TiO2 film mixed with TiO2-CNTs was annealed at 500 °C for 1 hour under atmospheric conditions, resulting in a film thickness of 10-15 μm.
- The passivation layer increases the adhesion property between the FTO glass and porous TiO2 layer, reducing the leakage current by preventing direct contact of electrolyte and FTO glass.
- SEM analysis shows that, on porous electrode, the TiO2-CNTs were entirely surrounded by TiO2 nanoparticles. Compared with a conventional TiO2 cell, the modified TiO2 cell (0.1 wt.% TiO2-CNTs) showed ~50% increase in the value of conversion efficiency. The enhancement in Jsc is attributed to the improved interconnectivity between the TiO2 particles and the TiO2-CNTs in the porous TiO2 film.

4. Low-temperature fabrication of dye-sensitized solar cells by transfer of composite porous layers

Michael Durr, Andreas Schmid, Markus Obermaier, Silvia Rosselli, Akio Yasuda, Gabriele Nelles

Overview:

- The process starts with the preparation of a thin gold layer, approximately 10–20 nm, on a glass substrate. On top of this gold layer a TiO2 layer, the so-called transfer layer, is applied. All process steps that are appropriate for the gold/glass substrate—among others, the application of temperatures up to above 500 ◦ C—can also be applied to the TiO2, ensuring a high-quality porous layer.
- The results for cells made according to the lift-off method show the best values for tetra-butyl ammonium iodide (TBAI) when sintering the adhesion layer at 200 ◦ C after the transfer process. TBAI treatment of standard cells does not change the efficiency at all.
- The adhesion layer consists of small TiO2 nanoparticles with an average diameter of 10 nm. It is printed onto the substrate by means of inkjet printing.Another important process step is low-temperature sintering.
- The advantages of the composite layer are manifold. (i) Comparable to those of earlier-introduced scattering layers,(ii) The TiO2 nanorods were shown earlier to show inherently good electron transport and photovoltaic properties.(iii) Most important from the point of view of the lift-off technique, we recognized that the removal from the spare substrate and thus the transfer of the composite layers consisting of spheres and rods (sphere–rod composite layers, SRCL) is greatly facilitated when compared with the removal and transfer of other layers.
- The shape of the TiO2 on the nanometre scale, in combination with the nanoporous arrangement of the particles in the layer, is correlated with the macroscopic differences in the mechanical properties of the layers, leading to the optimization of the lift-off process.

5. Fabrication of dye-sensitized solar cell based on mixed tin and zinc oxide nanoparticles

Mahsa Saeidi, Masoud Abrari, Morteza Ahmadi

Overview:

- The DSSC fabricated from a SnO2/ZnO ratio of 1:2 demonstrated the best electron lifetime and charge transport dynamics.One of the problems with TiO2-based DSSCs is their low stability under UV-illumination. This problem can be addressed by replacing TiO2 with other oxides.
- Preparing SnO2 and ZnO nanoparticles employing the sol–gel method and mix them with different weight ratios. After that, fabricate DSSCs based on the mixed SnO2/ZnO nanoparticles.SnO2/ZnO nanoparticles were mixed with different weight ratios of 1:0, 2:1, 1:1, 1:2 and 0:1. These powders were dispersed in 5 ml of pure ethanol and stirred for 1 h.
- To evaluate the amount of dye loading time required for each weight ratios of the SnO2/ZnO nanoparticles, the photoanodes remained in the dye solution for durations of 1, 2, 6, 12, and 24 h.
- Observe that the generated current in the cell prepared from the SnO2/ZnO ratio of 1:2 is the highest among other cells. Furthermore, the EIS results show that this cell demonstrates the longest recombination time (1180 ms), this can be used as a justification to explain that the longer recombination time in the cell increases the number of electrons reaching the FTO and thus reduces the loss.

6. Fabrication of Dye Sensitized Solar Cells Using Natural Dyes

Maheen Mazhar, Hafiza Mazia Ada, Humair Ahmed Siddiqui, Sadia Muniza Faraz

Overview:

- The use of natural pigments as dye solved difficulties such as cost, availability, and production complexity, while also providing a diversity of options from various portions of plants such as roots, barks, leaves, flowers, and fruits.
- In this work, DSSC is developed by using natural extracts of beetroot (Beta vulgaris) and Mango (Mangifera Indica) as dyes, potassium iodide (KI) as electrolyte, ITO coated glasses for preparation of both electrodes, carbon soot from a burning candle flame for counter electrode, and mesoporous TiO_2 film for photoanode production.
- Standard cleaning procedures are used to clean ITO coated glass, and its conducting side is detected using an ohmmeter. Titanium dioxide paste is applied evenly on the conducting side. The glass is allowed to dry after the TiO_2 thin coating is deposited. The dye is then dip coated and absorbed around the TiO_2 particles before being set away to solidify. The counter-electrode is made from another ITO coated glass, and its conductive side is exposed to a candle flame to deposit a thin layer of carbon. To complete the DSSC assembly, both electrodes are sandwiched together and secured in place with binder clips.
- The fabricated cells were examined in both dark and light environments. DSSCs fabricated from ethanolic mango extract provided promising results with highest Voc of 660mV and JSC of 0.00232mA/cm^2 with efficiency of 0.303%.
- The abundance of natural resources, straightforward preparation methods, environmental friendliness, reasonable efficiency, and affordable resources in the renewable energy sector make it simple to realize DSSCs.

7. Utilisation of Naturally Occurring Dyes as Sensitizers in Dye Sensitized Solar Cells

Nipun Sawhney, Anubhav Raghav, Soumitra Satapathi

Overview:

- Dye sensitized solar cells (DSSCs) were fabricated with four naturally occurring anthocyanin dyes extracted from naturally found fruits/juices (Indian jamun, plum, black currant, and berries) as sensitizers.
- Anthocyanins are one of the most abundant and widespread classes of natural pigments. They are natural dyes that are responsible for the color of many fruits, leaves, and plants. Because of the carbonyl and hydroxyl groups on the anthocyanin molecule, they can easily bond to the surface of TiO2 nanoparticles.
- Dyes obtained from black currant crush and mixed berries resulted in the most efficient DSSCs. Darker colored anthocyanins have been found to be more efficient. This is due to the fact that darker colors translate to increased light absorption, resulting in higher photocurrent densities.

8. Indoor Light Harvesting Using Dye Sensitized Solar Cell

Priya Poulose, P. Sreejaya

Overview:

- The paper discusses the potential of Dye Sensitized Solar Cells (DSSCs) as an energy harvester in indoor environments.
- While traditional silicon solar cells are limited in their ability to perform efficiently under low lighting conditions, DSSCs have better conversion efficiency and can absorb light from various indoor light sources.
- The paper explores the use of DSSCs to power wireless sensor nodes (WSNs) that work in the low power range, eliminating the need for additional batteries and reducing environmental impact.

- The stability and shelf life of DSSCs can be improved by using solid dye material and solid polymer electrolyte. The paper concludes by discussing the potential for developing biocompatible and biodegradable DSSCs.

9. Investigation of properties for dye-sensitized solar cells in series-parallel connection modules

Cheng-Chu Ko, Jung-Chuan Chou, Yi-Hung Liao, Chih-Hsien Lai, Chien-Hung Kuo

Overview:

- The paper investigates the properties of dye-sensitized solar cells (DSSCs) in series-parallel connection modules.
- The authors used conductive copper foil with a series-parallel combination tape to decrease contact resistance and encapsulated the DSSCs to measure their current density-voltage curves. The modules were able to drive a simple light bulb.
- The best photovoltaic conversion efficiency (η) of a single DSSC was 3.71%, but that of DSSCs in series-parallel decreased to 3.50% due to contact resistance.
- The authors investigated this phenomenon using an electrochemical impedance spectrometer (EIS) for internal impedances with an equivalent circuit model.
- The paper also describes the fabrication process of the DSSCs, including cleaning the FTO glasses, depositing platinum onto the glasses using a radio frequency (R.F.) sputtering coater, and injecting electrolyte into drilled holes on the counter electrode.

10. Development of dye-sensitized solar cell (DSSC) using patterned indium tin oxide (ITO) glass: fabrication and testing of DSSC

M. Mazalan, M. Mohd Noh, Y. Wahab, M. N. Norizan, I. S. Mohamad

Overview:

- The paper presents the development of a dye-sensitized solar cell (DSSC) using natural dyes extracted from mangosteen pericarp and maqui berry.
- The DSSC comprises a semiconductor electrode, counter electrode, and electrolyte. The semiconductor electrode is made of Titanium Dioxide (TiO2) and is deposited on a patterned Indium Tin Oxide (ITO) glass substrate.
- The absorption spectrum and transmission of the extracted dyes are analysed using UV-Vis spectrophotometer. The performance of the patterned DSSC is investigated in terms of fill factor, efficiency, and current density using a digital multimeter.
- The paper concludes that the efficiency of the patterned DSSC is improved for both of the dyes.

11. Research into dye-sensitized solar cells: a review highlighting progress in India

S Bera, D Sengupta, S Roy, K Mukherjee

Overview:

- During the early 1800s, the industrial revolution relied on fossil fuels, prompting a global shift towards lower emissions and carbon neutrality. India, recognizing its substantial solar energy potential, has made remarkable progress in solar research, particularly in photovoltaics.
- Dye-sensitized solar cells (DSSCs) have gained prominence due to their simple preparation, eco-friendliness, and appealing attributes.
- Indian researchers have focused on enhancing DSSC components, with notable attention on exploring alternative photoactive dyes, diverging from conventional N3 and N719 organometallic dyes.

- This paper highlights India's strides in optimising DSSC elements to harness solar energy efficiently.

12. Effect of Photoanode Design on the Photoelectrochemical Performance of Dye-Sensitized Solar Cells Based on SnO2 Nanocomposite

I-Ming Hung, Ripon Bhattacharjee

Overview:

- Li-doped ZnO (LZO) aggregated nanoparticles are employed as an insulating layer within SnO2 nanocomposite (SNC) photoanodes, effectively curbing recombination in dye-sensitized solar cells (DSSCs).
- By incorporating varying weight percentages of SnO2 nanoparticles (SNPs) and SnO2 nanoflowers (SNFs) in SNC photoanodes, increased conversion efficiency is achieved. The improved performance stems from heightened surface area, enhanced charge injection and collection, and reduced recombination rates.
- Electrochemical impedance spectroscopy (EIS) corroborates lower series and charge injection resistances, along with shorter lifetimes in DSSCs featuring LZO-insulated SNC photoanodes.
- Notably, open circuit voltage and fill factor are significantly elevated, with optimal results found in the SNC:SNF ratio of 1:1, yielding a current density of 4.73 mA/cm2, open circuit voltage of 630 mV, fill factor of 69%, and an efficiency of 2.06%.

13. Zinc Porphyrins Possessing Three p-Carboxyphenyl Groups: Effect of the Donor Strength of Push-Groups on the Efficiency of Dye Sensitized Solar Cells

Ram B. Ambre, Sandeep B. Mane, Chen-Hsiung Hung

Overview:

- Efficient zinc porphyrins, featuring three p-carboxyphenyl anchors and varying electron-donating substituents, were easily synthesized.
- Investigating their impact on power conversion efficiency, comprehensive analyses including photophysical, electrochemical, and spectroscopic methods were employed.
- Multi-anchor dyes exhibited greater stability and stronger binding to TiO2 surfaces compared to single-anchor counterparts, as evident from photophysical and IR data.
- These dyes offer advantages such as straightforward synthesis, high yields, scalability, and robust TiO2 adhesion, rendering them suitable for commercial applications.
- Remarkably, Zn1NH3A, possessing electron-donating and anti-aggregation properties, achieved an impressive 6.50% efficiency.

14. Towards Renewable Iodide Sources for Electrolytes in Dye-Sensitized Solar Cells

Iryna Sagaidak, Guillaume Huertas, Albert Nguyen Van Nhien, Frédéric Sauvage

Overview:

- A new series of iodide salts and ionic liquids derived from diverse carbohydrate cores is introduced for potential use in dye-sensitized solar cells (DSC).
- The study explores the impact of molecular structure and cation arrangement on electrolyte characteristics, device efficiency, and charge transfer at interfaces.
- Employed alongside the C106 polypyridyl ruthenium sensitizer, these carbohydrate-based electrolytes, coupled with a stable methoxypropionitrile (MPN) solution, achieved noteworthy power conversion efficiencies ranging from 5.0% to 7.3% under standard A.M. 1.5G conditions.
- This research highlights the promise of these sugar-derived iodide sources in enhancing DSC performance.

15. Inorganic p-Type Semiconductors: Their Applications and Progress in Dye-Sensitized Solar Cells and Perovskite Solar Cells

Ming-Hsien Li, Jun-Ho Yum, Soo-Jin Moon, Peter Chen

Overview:

- Given the escalating global energy demand and environmental concerns tied to conventional sources, the imperative for clean and renewable energy is evident.
- Solar energy, abundant and eco-friendly, aligns with alternative energy objectives. Dye-sensitized solar cells (DSCs), exemplified by their cost-effectiveness, versatility, and potential applications, offer a promising avenue for large-scale sunlight-to-power conversion.
- While n-type semiconductor sensitization is well-explored, recent attention has shifted to p-type semiconductors. These inorganic materials, crucial for charge selectivity and transport in perovskite solar cells (PSCs), exhibit a significant influence on solar cell performance.
- This review delves into p-type DSCs and PSCs integrated with inorganic p-type semiconductors, presenting recent findings and offering insightful perspectives.

16. Research Progress on Photosensitizers for DSSC

Carella Antonio, Borbone Fabio, Centore Roberto

Overview:

- The rise in global energy demands is a significant societal challenge, with the International Energy Outlook 2017 predicting a 28% increase in global energy consumption between 2015 and 2040. The depletion of fossil fuels and their environmental impact have led to the development of clean and renewable energy sources, such as solar energy. DSSC, a promising alternative to traditional silicon-based solar cells, offers low-cost fabrication methods, compatibility with conventional roll-to-roll techniques, and compatibility with flexible substrates, textiles, and paper. DSSC devices are semi transparent and can be made in various colors, making them attractive for integrated photovoltaics.

- The device consists of a mesoporous metal oxide semiconductor with a dye, deposited on a transparent electrode and supported on a substrate. The working electrode, photoanode, is supported by a transparent conductive layer. The device operates through a multistep process, with an electron injected, collected, and transferred to the counter-electrode, regenerating the original dye.
- DSSC is a multicomponent device with extensive investigation of components, sensitizers, and other components for efficiency improvement. Ru(II) polypyridyl complexes are the first generation of DSSC sensitizers, with molecular engineering strategies aiming to increase light harvesting capacity and long-term stability. Porphyrin-based photosensitizers are highly sought after due to their impressive absorption coefficients. Cobalt-based electrolytes have been used to maximize efficiency, with efficiencies of up to 13% achieved when combined with redox mediators.
- DSSCs are expected to gain market share for superior indoor performance in portable electronics. However, increased efficiency, stability, and cost reduction are needed for commercialization. Studies have explored molecular structures as potential DSSC photosensitizers, but challenges like stability and photodegradation remain. Organic dyes with silyl anchoring groups could be explored for improved performance.

17. Research on dye sensitized solar cells: recent advancement toward the various constituents of dye sensitized solar cells for efficiency enhancement and future prospects

Sultana Rahman, Abdul Haleem, Muhammad Siddiq, Muhammad Khalid Hussain, Samina Qamar, Safia Hameed, Muhammad Waris

Overview:

- Global energy demand is a significant challenge, leading to the development of clean, renewable energy sources like solar energy. Dye Sensitized Solar Cells (DSSC) offer low-cost fabrication methods, compatibility with flexible substrates, textiles, and paper, and are semi transparent. DSSCs require improved efficiency, stability, and cost reduction for commercialization. However, challenges like stability and photodegradation remain.

- Global research on DSSC components has been significant in the past decade, with no material found to increase efficiency. Most efforts focus on affordable, eco-friendly, stable, and effective DSSCs. TiO_2 and ZnO are the most researched photoanode materials, with TiO_2-modified photoanodes like $SiO_2/Ag/TiO_2$, g-C_3N_4, and ZnO/TiO_2 demonstrating promising photovoltaic capabilities. ZnO-based photoanodes show promising electron transport and increased cell efficiency. Organometallic dyes based on ruthenium are considered crucial for DSSCs.
- DSSCs convert light energy into electrical energy through sensitization of semiconductor wide band gaps. They consist of sensitizers, photocathodes, electrolytes, counter terminals, and substrates with transparent conductive oxide (TCO) layers. Fine conductive glass is used for its affordability, accessibility, and optical transparency. A transparent conductive oxide film, like indium-doped tin oxide or fluorine-doped, maintains a minimal electric charge for each area, with a resistance of 10-20 Ω^{-2}.
- A photoelectrode is a nanostructure material connected to a translucent substrate. Titanium dioxide is a cheap, harmless, and abundant material used in semiconductors. TiO_2 nanoparticles are typically 15-30 nm in size and thickness. Sintering occurs between 450 and 500°C, forming a permeable electrode. The electrode is dye-sensitized by immersing it in a dye solution. Research has shown that carbon nanotubes (CNT) can acclimate to titania photoanodes, resulting in reduced resistance, charge injection, and longer electron lifespan. This technology is ideal for productive DSSCs, as it enhances charge and division properties. Additionally, graphene-titanium dioxide nanocomposite photoanodes have been developed, with smaller graphene sheets resulting in increased conversion productivity.
- Over the past 20 years, DSSCs have shown promise in flexible solar cells due to their flexibility, lightweight, and environmental friendliness. Researchers have used doctor blade approaches to coat thin-film samples with TiO_2 and ZnO, achieving 1.21% efficiency. However, plastic-type substrates face challenges due to temperature limitations, resulting in poor nanoparticle connectivity and higher electrode resistance. Various techniques are being studied for more efficient flexible DSSCs, including titanium(iv) tetraisopropoxide or UV-O_3 treatment.

- Numerous studies have been conducted on DSSC to improve their efficacy and viability. However, NDSSCs are inferior to synthetic DSSCs due to inefficiency, dye degradation, and temperature stability concerns. Synthetic dyes, like ruthenium, are more stable than natural colors and can improve DSSC performance. Solid electrolyte DSSCs are being researched, but their proficiency is lowered. DSSCs exhibit low absorption in the red portion of the sun spectrum, which can be resolved through sensitizer enhancements. Challenges in large-scale manufacturing and widespread adoption of DSSC innovation hinder their widespread adoption.

18. Advanced research trends in dye-sensitized solar cells

Mikko Kokkonen, Parisa Talebi, Jin Zhou, Somayyeh Asgari, Sohail Ahmed Soomro, Farid Elsehrawy, Janne Halme, Shahzada Ahmad, Anders Hagfeldt, Syed Ghufran Hashmi

Overview:

- This paper reviews the recent progress in research on dye-sensitized solar cells (DSSCs) towards the goal of scaling their fabrication methods to industrial manufacturing with high photovoltaic efficiency and performance stability under typical indoor conditions.
- The paper discusses the development of new device structures, alternative redox shuttles, solid-state hole conductors, TiO2 photoelectrodes, catalyst materials, and sealing techniques to improve each functional component of a DSSC.
- The paper proposes a scalable cell fabrication process that integrates these developments to a new monolithic cell design based on several features including inkjet and screen printing of the dye, a solid-state hole conductor, PEDOT contact, compact TiO2, mesoporous TiO2, carbon nanotubes counter electrode, epoxy encapsulation layers, and silver conductors.
- Finally, the paper discusses the need to design new stability testing protocols to assess the probable deployment of DSSCs in portable electronics and internet-of-things devices.

19. A Study on the Application of Solar Cells Sensitized With a Blackberry-Based Natural Dye for Power Generation

Alamry Ali, Shukur Abu Hassan, Amal BaQais, J. S. Binoj

Overview:

- This research paper evaluates the use of natural dyes from blackberry for their application in laboratory solar cells to generate electrical energy.
- The study aims to reduce the high demand generated by global warming by using natural dyes from plant species as a supplement to improve efficiency in capturing renewable energy (solar) and converting it into electrical energy.
- The study used six solar cells sensitized with natural dyes, which were tested for their ability to absorb ultraviolet and visible light using a spectrophotometer in the ultraviolet-visible range, a solar simulator, and a current-voltage tester.
- The paper also discusses the validation of the pH of the blackberry colorant, the use of a porcelain mortar for grinding and mixing substances, and the use of electronic scales and Erlenmeyer flasks in the laboratory.
- In summary, the paper explores the use of natural dyes from blackberry for generating electrical energy in solar cells and provides a detailed methodology for the same.

20. The Basic Research on the Dye-Sensitized Solar Cells (DSSC)

Arini Nuran Binti Zulkifili, Terauchi Kento, Matsutake Daiki, Akira Fujiki

Overview:

- This research paper focuses on the dye-sensitized solar cell (DSSC), a new type of solar cell that converts visible light into electricity using a photoelectrochemical system.
- The paper evaluates the particle size of titania, the effects of molecular binder PEG towards TiO_2 paste preparation, the effects of natural dye, and the effect of the multilayer of TiO_2.
- The paper also discusses the fabrication of DSSC using TiO_2 powder, acetic acid, pure water, polyethylene glycol, acetylacetone, iodine electrolyte, graphite carbon pencil, and FTO.

MATERIALS AND METHODOLOGY

1. Materials required:

- Titanium dioxide (titania-TIO2).
- Nitric acid in small amounts.
- Fluorine / Indium doped tin oxide conducting glass.
- Berry juice - Raspberry, Blackberry dyes, OR Artificial dyes.
- Redox electrolyte - Iodine, Potassium iodide, ethylene glycol.
- Scotch tape for borders.
- Multimeter.
- Binder clips.
- Graphite - pencil lead

TiO2 Powder

ITO Glass

Redox Electrolyte

Natural Dye

Nitric Acid

Multimeter

Graphite

Binder Clip

2. Methodology

STEP 1: CURRING THE PASTE - TIO2 MIX

1. Prepare the TiO2 paste: Take the TiO2 powder and mix it with nitric acid to achieve the desired consistency. The paste should be neither too liquid nor too pasty to ensure proper application.

2. Identify the coated side of the glass plate: Determine which side of the ITO-coated conducting glass plate is coated. This can be done by observing which side is more shiny or by using a multimeter to check for 0-ohm resistance on the coated side.

3. Mask the glass plate: Apply tape to the ITO-coated side of the glass plate, creating a square exposed surface where the TiO2 paste will be applied.

4. Apply the TiO2 paste: Put the TiO2 paste on the exposed square area of the ITO-coated glass plate. Ensure that the paste is applied uniformly to achieve a consistent thickness.

5. Spread the paste: Use another glass plate or a rod to spread the TiO2 paste across the coated area. The goal is to achieve a smooth and even layer of the TiO2 paste on the conducting glass plate.

After completing these steps, the TiO2 layer is ready for further processing and dye-sensitization, which is a critical part of DSSC fabrication.

STEP 2: DRYING AND LOW-TEMPERATURE SINTERING

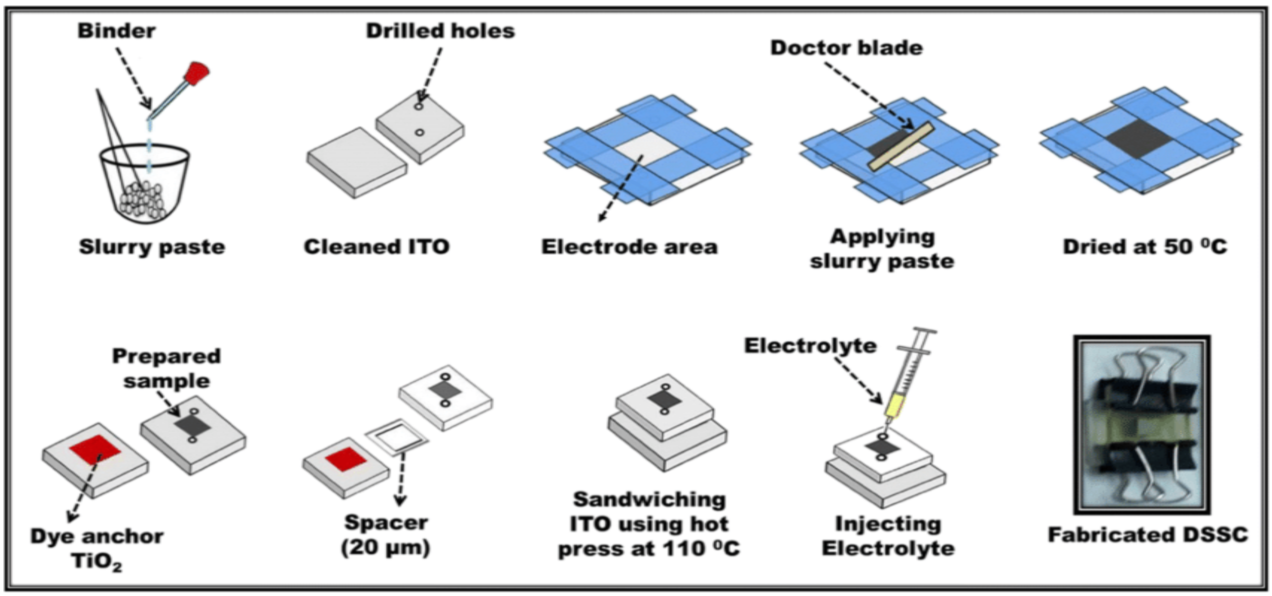
1. Drying the TiO2 paste: After applying the TiO2 paste to the ITO-coated conducting glass plate, allow it to dry for about 1 hour. During this drying process, the colour of the paste may change due to solvent evaporation and oxidation of TiO2 particles.

2. Sintering at low temperatures (if necessary): Ideally, the TiO2 layer should be sintered at temperatures around 450-500°C for 2-3 hours to achieve optimal properties. However,

since low-temperature sintering is being considered due to equipment limitations, place the glass plate on a heater and set the temperature somewhere between 120-150°C. Let it heat for 2 hours to allow partial sintering.

3. Colour change after sintering: After the specified sintering time, there might be further colour changes in the TiO2 layer due to continued solvent evaporation and increased bonding of TiO2 particles.

The drying and sintering steps are crucial for forming a stable and well-adhered TiO2 layer, which is the key component for the efficient operation of the DSSC.



STEP 3: DYEING THE ANODE LAYER

1. Prepare the glass plate: Ensure the glass plate is clean and free from any contaminants that could interfere with the dye absorption process.

2. Dip the glass plate in dye: Once the glass plate is taken out of the hot plate, immerse it in the prepared dye solution contained in a beaker or petri dish. The dye should be chosen based on factors like absorption range, stability, cost, and efficiency. As mentioned, organic or artificial dyes can be used.

3. Dye absorption: Allow the glass plate to sit in the dye for a specific duration, ideally one full night. However, for the purpose of your college project, 2-3 hours of dye absorption may be sufficient to observe some results.

4. Rinse with ionized water: After the desired absorption time, take the glass plate out of the dye solution and rinse it thoroughly with ionized water. This step is essential to remove any excess or unabsorbed dye from the surface of the glass plate.

5. Final rinse with isopropanol: To ensure complete drying and remove any remaining water content, rinse the glass plate with isopropanol, which acts as a drying agent.

6. Result: At this stage, you will have the anode layer of the DSSC prepared with the dye absorbed onto the TiO2-coated glass plate.

The choice of dye, as mentioned, is crucial as it determines the absorption properties of the DSSC. Organic dyes, such as anthocyanins found in fruit juices, can be used for educational purposes to demonstrate the principles of DSSCs. More advanced DSSCs may use artificial dyes like ruthenium-based or pyridine dyes for higher efficiency and stability.

STEP 4: CATHODE-COUNTER ELECTRODE PREPARATION AND ELECTROLYTE

1. Prepare the cathode: Take the other ITO-coated glass plate and coat it with a layer of graphite by rubbing a pencil on the surface. Graphite acts as a catalyst to facilitate the reaction in the DSSC.

2. Add redox electrolytes: To enable conductivity in the DSSC, add redox electrolytes, such as iodine, potassium iodide, and ethylene glycol. Triiodide is one of the commonly used redox electrolytes in DSSCs.

3. Assemble the cell: Place the two prepared glass layers on top of each other with their conductive sides facing together. Ensure that the edges are offset, allowing space for the connections later on. Use binder clips to hold the glass layers together firmly.

4. Introduce the electrolyte: Loosen the binder clips slightly to create openings between the conductive layers. Add the redox electrolyte drop by drop into these openings, ensuring that the electrolyte is correctly placed and distributed.

5. Secure the assembly: After adding the electrolyte, tighten the binder clips again to seal the cell and prevent any leaks.

6. Test the DSSC: With the DSSC fully assembled, it is now ready to be tested. Expose the cell to light and measure its electrical output to observe its photovoltaic performance. The efficiency and performance of the DSSC may vary depending on the quality of materials used and the precision of the fabrication process.

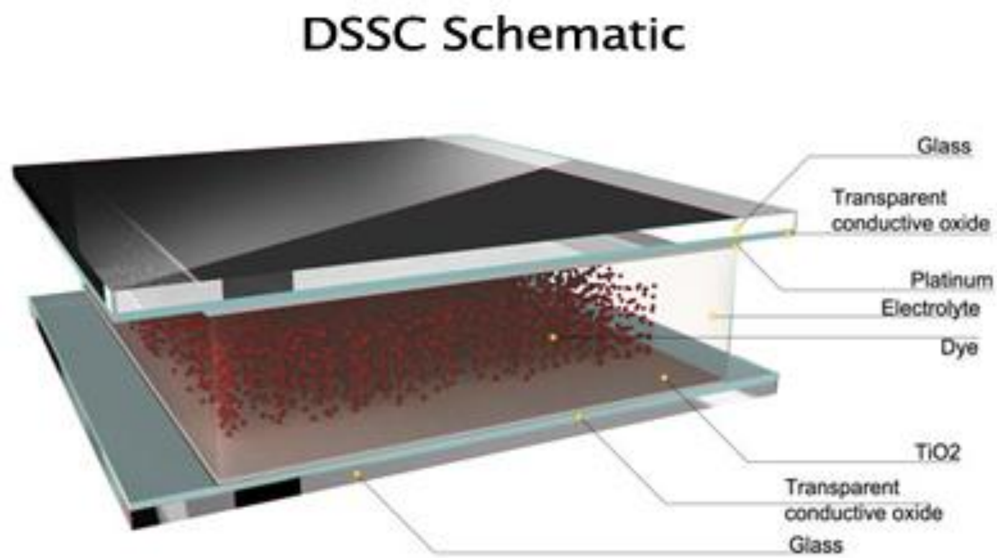
STEP 5: TESTING AND ANALYSIS

1. Connect the multimeter: Set the multimeter to measure voltage and connect it to the DSSC using alligator clips. One clip should be connected to the ITO-coated side of the anode (TiO_2-coated glass plate) and the other clip to the graphite-coated side of the cathode (the other ITO-coated glass plate).

2. Expose the cell to light: Ensure that the DSSC is exposed to light. You can use a bright light source or, ideally, natural sunlight for testing.

3. Observe voltage readings: With the DSSC exposed to light, the multimeter should show some millivolt (mV) readings. The voltage readings should increase as the intensity of the light shining on the cell becomes brighter.

The increase in voltage readings with brighter light is a characteristic behaviour of photovoltaic devices like solar cells. It indicates that the DSSC is generating electricity in response to the incident light.The voltage generated by a single DSSC may be relatively low, especially in small-scale setups like those used for educational projects. However, when connected in series or parallel, multiple DSSCs can generate higher voltages and currents.



RESULTS AND DISCUSSION

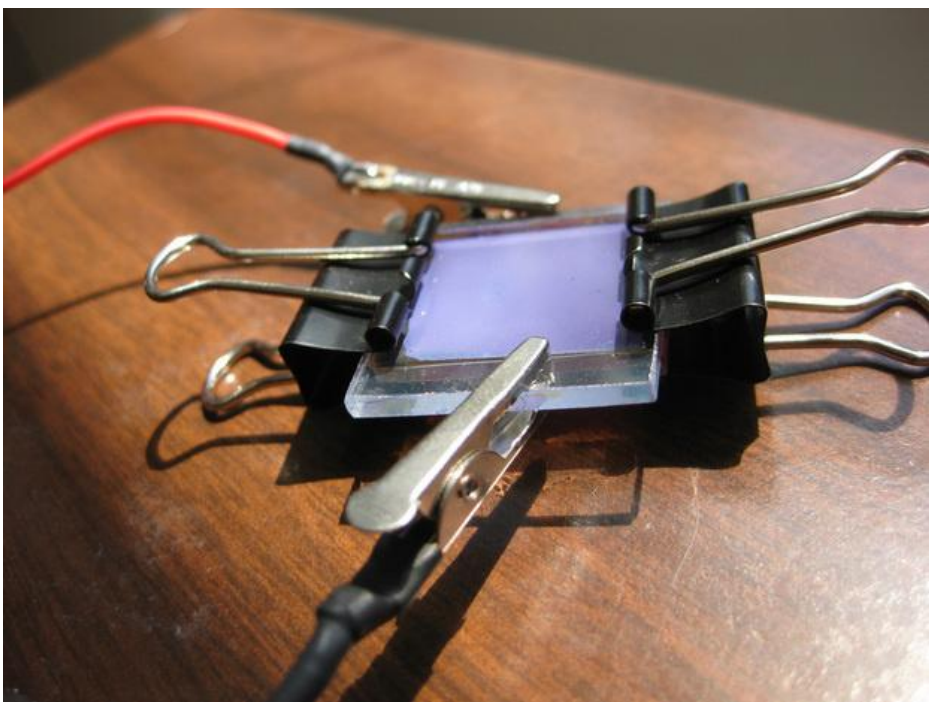
Creating a DSSC (Dye-Sensitized Solar Cell) model as a project in college had a positive impact on our academic as well as our practical fields. As we got hands-on experience on how to fabricate a solar cell, the intricacies involved in gathering the materials for writing a professional showcased report. DSSCs are a type of thin-film solar cell that has garnered interest for their potential to convert sunlight into electricity.

The results which are/would be after building a model and implementing the required research come out as:

1. **Learning Opportunity:** Building a DSSC model involves understanding the principles of semiconductor physics, photon absorption, electron transfer,etc. I believe our team would have got some valuable insights after performing and building a model. We would learn deeply about vast topics which are provided by some renowned research authors.
2. **Interdisciplinary Knowledge:** DSSC projects bridges the gap between different disciplines such as physics, chemistry, material science, and engineering. This enhanced our team's abilities to work on different aspects and topics involved.
3. **Hands-On Experience:** Working with DSSCs involves practical experimentation, which can develop skills in laboratory techniques, equipment handling, and data analysis.
4. **Problem-Solving Skills:** Throughout this project members of our team will be encountering a variety of obstacles like choosing suitable and compatible materials required, troubleshooting some technical or physical issues, solving these without intuition and skills would help us sharpen our brain skills.
5. **Renewable Energy Awareness:** By working on a project related to renewable energy, we can raise awareness about the importance of sustainable energy sources and their potential to address environmental concerns.
6. **Innovation and Creativity:** Developing a DSSC model involves trying out various materials for the cell components, experimenting with different dye sensitizers, and exploring novel designs.This made us rekindle our creative thoughts to create a appealing model.
7. **Research Opportunities:** DSSCs are an active area of research with ongoing developments. If some of our teammates would pick up interest in this topic and would

want to further dive into this topic, there are abundant opportunities in our college and outside world.

8. **Networking and Collaboration:** As collaboration and people management are one of the crucial soft skills required for a college student's projects, collaborations like these serve as a goldmine for these networking and making some real friends along the way.
9. **Presentation and Communication Skills:** Presenting the project's findings to peers, faculty, and potentially at conferences can improve our ability.
10. **Practical Application:** If the DSSC model yields positive results, it might serve as a proof-of-concept for potential applications in renewable energy systems, encouraging further exploration and development.



Proposed Prototype of Dye Sensitised Solar Cell

OBJECTIVES

The objectives for future presentations and model making would be focusing both on educational and practical aspects such as:

1. **Understanding the underlying principles:** To understand thoroughly the basic working principles of a typical DSSC solar cell with all its concepts like the Photovoltaic effect, electron transfer, reaction mechanisms, etc.
2. **Knowledge demonstration:** To be able to explain the concepts behind the working clearly. To gain a ground-level understanding of the technology behind DSSC and to be able to explain it to the audience using presentations, charts, and images.
3. **Model demonstration:** Build a physical DSSC model using the mentioned components and their arrangement by utilising proper ITO layers, TIO2 powder, and dyes, and show its working in appealing and representing key components.
4. **Efficiency and Experimental testing:** Conduct a simple experiment on the demonstration of the DSSC model and record some test values in different lighting conditions and measure the varying outputs to different inputs. Optimising the value for near-perfect efficiency and high performance.
5. **Comparative analysis with different existing solar cells:** Do a strategic comparison of other solar cells like silicon-based cells, and nano-particle-based cells, and highlight the advantages of DSSC in terms of cost, applications, and production.
6. **Real-world applications and environmental impact:** Educate about the sustainability of DSSC over other solar cell technologies, its off-grid, and portable applications. Flexibility and some niche-specific usage of DSSC. Address the natural materials used in the manufacture of cells and their impact in the long run on the environment.

CONCLUSION

Dye-sensitized solar cells (DSSCs) have been extensively studied worldwide for the past three decades to explore alternative photovoltaic devices. These cells consist of the photoanode, dye, electrolyte, and counter electrode. Researchers have focused on improving their photoconversion efficiencies and long-term stability. However, the commercial viability of DSSCs is challenging due to their lack of long-term stability. The maximum efficiencies in DSSCs were obtained using costly Ru-based organometallic dyes.

Indian researchers have contributed significantly to the study of dye sensitizer-based solar cells. Nanostructure materials and doped materials are crucial for energy efficiency conversion, with nanostructure-doped materials showing high efficiency. Future research on DSSC improvement will involve nanostructure and doping materials. New dyes with natural origins are also being reported, emphasising the need for sensitizers with suitable properties for energy harvesting and low-cost manufacturing methods. DSSCs are developed as a cheap alternative, but their efficiency is not sufficient. To address this, a comprehensive approach is needed, focusing on electrodes, photosensitizers, and electrolytes.

In terms of commercial applications, DSSCs need to be sustainable for over 25 years in building-integrated modules and have a lifespan of 5 years for portable electronic chargers integrated into apparel and accessories. However, DSSCs are bulky due to their sandwiched glass structure, and flexible DSSCs can be processed using roll-to-roll methods but compromise their shorter lifespan. Additionally, selecting metal interconnects in cells that are more or less corroded to the electrolyte and controlling cell-to-cell reproducibility are challenges. If these challenges are overcome, there is no roadblock for commercial applications of DSSCs, which have been restricted to an amicable extent.

FUTURE SCOPE

Dye-Sensitised Solar Cells have become a prominent topic in the field of renewable energy and photovoltaics. DSSC has significant advantages such as cost-effectiveness, simple fabrication procedures, and the possibility for flexibility and transparency. To improve efficiency, try out novel sensitizers, optimize dye composition, and construct photoelectrode interfaces to promote light absorption and electron transport. The search for new sensitizer materials, such as novel dye compounds with improved light-absorbing properties, stability, and appropriate energy levels, continues.

Alternative electrolytes, including solid-state electrolytes, ionic liquids, and redox mediators, are being investigated to increase stability, reduce leakage, and improve short and long-term performance. Bridging the gap between laboratory-scale prototypes and large-scale production is critical for the commercial viability of DSSCs.

Once good laboratory results are obtained, research activities can shift to scalable manufacturing. Scientists are investigating methods to store and manage the energy generated by DSSC, with the goal of improving its practical application in energy systems. Integration with energy storage and smart grid technology. It is possible to examine integration with energy storage technologies and smart grid systems. Future prospects are also dependent on the environmental impact and sustainability of improving DSSC, which makes the process a sustainable manufacturing practice.

1. **Improved Charge Transport**: Enhancing charge transport within the DSSC structure can lead to higher efficiency. Researchers can come up with new materials and strategies to minimize recombination losses and improve electron and hole mobility. Nanostructured Electrodes: Designing nanostructured photoelectrodes can increase the surface area for dye adsorption and improve electron transport. Advancements in nanomaterials and fabrication techniques can be explored for this purpose.
2. **Interface Engineering:** The interfaces between different layers in the DSSC play a crucial role in charge separation and collection. Optimising these interfaces through molecular engineering and surface modification could lead to better and improved device performance.

3. **Transparent Conductive Electrodes:** Developing cost-effective and highly transparent conductive materials for the counter electrode is essential, especially for applications in building-integrated photovoltaics (BIPV) and other transparent electronics..
4. **Stability and Durability Enhancement:** Addressing the stability and degradation issues integrated with DSSCs is a continuous challenge. Research efforts can focus on understanding degradation mechanisms, exploring protective coatings, and developing new materials for improved long-term stability.
5. **Flexible and Printable DSSCs:** Developing flexible and printable DSSCs could enable applications in curved surfaces, wearable electronics, and flexible electronics. Research in this area could involve investigating flexible substrates, conductive materials, and fabrication methods.
6. **Integration with Energy Storage:** Integrating DSSCs with energy storage systems like batteries and supercapacitors can lead to hybrid energy systems with improved energy utilisation and supply stability.
7. **Environmental Sustainability:** Focusing on environmentally friendly materials, manufacturing processes, and recycling methods will become sustainably important as renewable energy technologies as DSSCs move toward wider adoption.
8. **Commercialization and Manufacturing:** Bridging the gap between laboratory research and large-scale production is crucial for the practical use of DSSCs. Developing scalable and cost-effective manufacturing processes will be a key aspect of future development.

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