

**Construction of DSSC using Nanostructured Cu/N co-doped TiO₂
Photoanode and MWCNT@rGO as Counter electrode using
Phenothiazine derived organic Photosensitizer.**

Submitted in partial fulfillment of the requirements for the award of a Bachelor of
Engineering degree In Chemical Engineering

by

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**DEPARTMENT OF CHEMICAL ENGINEERING
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SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

**Accredited with grade "A" by NAAC 12B status by UGC I Approved by AICTE
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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of ARUN.K.G (39190002) and HARSHVARDHAN RATHORE(39190008) who carried out the project entitled "Construction of DSSC using Nanostructured Cu/N co-doped TiO₂ Photoanode and MWCNT@rGO as Counter electrode using Phenothiazine derived organic Photosensitizers." under my supervision from January 2023 to MAY 2023.

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ABSTRACT

In dye-sensitized solar cells (DSSCs), TiO_2 has long been a popular electron transport material for carrying photo-generated electrons from the dye to the outer circuit. However, increasing the electrical conductivity of TiO_2 while preserving its properties is one of the most significant challenges for increasing DSSC efficiency. Here, Pure and Copper/Nitrogen (Cu/N) co-doped TiO_2 photoanodes with various Cu concentrations are prepared via sol–gel route for the photoanode also together controlled the particle size as well as narrowed bandgap of nanoparticles as determined by XRD and UV-Vis absorption measurements application in dyesensitized solar cells (DSSCs). A counter electrode core-shell heterostructure of multiwalled carbon nanotube@reduced graphene oxide nanoribbon (MWCNT@rGONR) was prepared by modified microwave-assisted synthesis step and a chemical reduction. The counter electrode (CE) of a dye-sensitized solar cell (DSSC) was made using a catalytic film made of the core-shell heterostructure of MWCNT@rGONR. One of the essential parts of DSSCs, metal-free organic dyes, are crucial to light harvesting and electron injection. Among the numerous types of organic dyes, colours based on 10H-phenothiazine have a significant share. Therefore, the structural characteristics of dyes based on 10H-phenothiazine ensure the creation of effective DSSCs. Some 10H-phenothiazine-based dyes show high photovoltaic performance, even better than the commercial ruthenium complex (N719). To form quasi-solid state electrolytes for dye-sensitized solar cells (DSSCs) , without using any volatile organic solvent electrolytes showed a higher thermal stability and conductivity due to the charge transport networks formed in the gel electrolytes via the p–p stacked gel electrolyte showed a superior long-term stability offered a feasible method to fabricate quasi-solid-state DSSCs in future practical applications.

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CHAPTER 1

INTRODUCTION

Dye-sensitized solar cells (DSSCs) have emerged as a scientifically and economically viable substitute for p-n junction photovoltaic systems. It was discovered in the late 1960s that electricity may be generated by igniting natural dyes in electrochemical devices. The University of Berkeley in California used spinach to isolate chlorophyll. (photosynthesis). The first chlorophyll-sensitized zinc oxide electrode was built in 1972. Initially, photons were converted into electricity by inserting excited dye electrons from molecules into a semiconductor with a large band gap. Numerous studies on ZnO single crystals have been conducted, however, the efficacy of these dye-sensitized solar cells was rather low since the monolayer of the dye molecules could only gather 1% of the incoming light. To increase the absorption of dye over the electrode and, hence, the light-harvesting performance (LHP), the efficacy of the electrode constructed of fine oxide powder was improved. As a result, in 1991, nanoporous titanium dioxide electrodes with a toughness factor of around 1000 were discovered, and 7% efficient DSSCs were created. These cells, known as Grätzel cells, were invented in 1988 at the University of California at Berkeley by Brian O'Regan and Michael Grätzel and were refined until 1991 at Ecole Polytechnique Fédérale de Lausanne (EPFL). TiO₂ nanoparticles with a large surface area and great optical transparency are coated with a single layer of a charge transfer dye with outstanding spectrum properties to make the film light harvesting responsive. Brian O'Regan and Michael Grätzel created this device. The device demonstrated extraordinarily high efficiencies, even exceeding 80% for converting of incident photons to electric current, and captured a significant portion of the 46% coming solar energy flow. The total incident photon to current conversion efficiency (IPCE) output in synthetic solar light was 7.1-7.9%, and it was 12% in diffuse daylight. The practical use was made possible by the high short circuit current density JSC (greater than 12 mAcm²), amazing stability (which stands at least five million rotations without decomposition), and low cost. In

1993, Grätzel et al. reported a cell effectiveness of 9.6%, while in 1997, the researchers at the National Renewable Energy Laboratory claimed a cell efficiency of 10%. (NREL). Sensitizers are typically synthesized using functional groups such as -COOH , $\text{-PO}_3\text{H}_2$, and -B(OH)_2 for stable attaching to the semiconductor substrate. Costa et al. have achieved an efficacy of 8.75% for hybrid dye-titania nanoparticle-based DSSC for improved low-temperature performance. In a typical solar cell, Si performs two functions: it creates photoelectrons and offers a field of electricity that separate the electrons and produces an electrical current. However, photosensitive pigments supply the photoelectrons in DSSCs, whereas the majority of the semiconductors is just used as charge carrier. Since the purportedly expected efficiency of power conversion of DSSCs was only around 20%, significant research on DSSCs has been conducted over the years to improve efficiency and encourage commercialization. Several research have been conducted in recent decades to improve the efficiency of DSSCs. For example, if one examines review papers or publications from 1920 and 1921, one may see a significant difference in the efficiency and construction of these cells. A few review articles are examined here, with the objective and major findings provided in a corresponding section, to get an understanding of how the functioning of these cells has been improved and, as a result, how the DSSCs emerged a hot topic for researchers. Anandan studied the achievements and emerging difficulties in dye-sensitized solar cells till 2007. He demonstrated how light gathering artificial pigment molecules, p-CuO nanorod counter the electrodes, and the self-organized structure of electroactive polymers work in a well-designed solar cell. However, the highest IPCE of 7% indicated in the review study for the naphthyridine coordination Ru complex and effective up to 2007 is just under fifty percent of the efficiencies attained in subsequent research. Bose et al.'s review study focuses mostly on the status of research and advancements in the disciplines of photoelectrode, photosensitizer, and electrolytes for DSSCs up to 2015. They did an intriguing investigation using a graph to contrast the performance of the DSSC module with that of the Si-based module and ultimately reached their conclusion that the DSSC module performed much better than the Si module. Furthermore, the DSSC based on phenothiazine

dye had the highest effectiveness while with an efficiency of 11.2% across this review research. Shalini et al. stressed sensitizers that include ruthenium materials, metal-free organic dyes, quantum-dot sensitizers, perovskite-based sensitizers, mordant dyes, and natural dyes. Although this site is highly knowledgeable on the many types of sensitizers, it lacks information on other critical DSSC components. Again, Jihuai Wu et al.'s review study focused on the counter electrode element rather than addressing all of the other DSSC components. Metals and alloys, carbon materials, conductive polymers, transition metal compounds, and combinations have all been investigated in relation to the exploration of various counter electrode types. The DSSC with Au/GNP as the counter electrode, $\text{Co}^{3+}/\text{Co}^{2+}$ as the redox couple, and LEG4 + ADEKA-1 as the sensitizer was described and verified to have a maximum efficiency of 14.3% in the review paper. Similarly, Yeoh et al. and Fan et al. offered a short overview of the DSSC photoanode. They classified photoanode modification into three categories: interfacial modification with prohibiting and scattered layers, compositing, doping with non-metallic anions and metallic cations, interfacial technology, and substituting traditional mesoporous semiconducting metal oxide films with 1-D or 2-D nanostructures. Solar cells that are dye-sensitized are considered the most feasible third generation solar cells due to their high performance, low cost, fast throughput, and environmentally friendly manufacturing technique. A conventional DSSC consists of a TiO_2 the photoanode containing dye decorations, a solution, and a counter electrode with platinum coating. In 1991, M. The first DSSC, built by Gratzel and his colleagues, had a power conversion rate of around 7%. So far, a peak power transfer rate of 14.1% has been achieved, suggesting a viable replacement for ordinary silicon solar cells. DSSCs, like traditional Si-based solar cells, have problems such as instability and poor power conversion efficiency. titanium dioxide is one of the most thoroughly studied semiconductor-oxide materials for DSSC photoanode applications as well as other photocatalysis processes such as hydrogen production, water purification, and air purification due to its inexpensive nature, nontoxicity, high stability, and high energy conversion efficiency. A considerable amount of effort has been discussed in the literature to improve

the efficacy of TiO_2 via metal doping (Ag, Au, W, Zn, Cd, Zr, and Cu) and nitrogen doping. TiO_2 is one of the most thoroughly studied semiconductor-oxide materials for DSSC photoanode applications as well as other photocatalysis processes such as hydrogen production, water purification, and air purification due to its inexpensive nature, nontoxicity, high stability, and high energy conversion efficiency. A considerable amount of effort has been discussed in the literature to improve the efficacy of TiO_2 via metal doping (Ag, Au, W, Zn, Cd, Zr, and Cu) and nitrogen doping. Based on these findings, we demonstrate the effective fabrication of entirely pure Cu/N-doped tiny particles of TiO_2 using a modified sol-gel method. These materials were then successfully included into DSSCs. The combined impact of Cu and N doping on the efficiency of TiO_2 NPs was examined by varying the Cu content while maintaining the N% constant. In addition, the photovoltaic characteristics of pure and Cu/Ndoped TiO_2 NP-incorporated photo anodes were investigated. Carbonaceous materials such as graphite, diamond, fullerene, amorphous carbon, active carbon, carbon black (CB), carbon nanotubes, and graphene (GN) are examples of aceous substances that have undergone extensive research in a variety of disciplines because the physical and chemical properties of carbon vary significantly depending on the shape it takes. Certain allotropic forms of carbon are gaining popularity for electrochemical applications such as fuel cells, lithium-ion batteries, hydrogen storage, sensors, and supercapacitors. This is attributed mostly to their exceptional electrical conductivity, chemical stability, and electrocatalytic capability. These materials have a high potential to replace expensive materials, lowering the cost of related items while improving their performance and longevity. The counter electrode (CE) of a dye-sensitized solar cell performs two functions: it collects the electrons from the photoanode and transforms triiodide ions (I_3) in the fluid to iodide ions (I). A conducting glass with a Pt catalytic layer is often used as the CE of a DSSC due to its excellent electrocatalytic efficiency for I_3 reduction and shown chemical durability⁶. Despite its high catalyst capacity for I_3 reduction and good electrical conductivity, Pt is rather expensive and must therefore be considered for cost-effective DSSC construction. Pt must be replaced with less costly materials like as conductivity polymers, transitioning metallic

compounds, and carbon-based allotropes to reduce the cost of making the cells, particularly when large-scale manufacturing is involved. Numerous carbon-based substances, such as multiwalled nanotubes made of carbon (MWCNT) or single-wall carbon nanotubes (SWCNT), along with activated carbon, CB, acetylene-black sphere-shaped, hard carbon spherules, 9a graphite, and others, have emerged as potential materials to replace Pt due to their low cost, high conductivity, and effective catalytic capacity for I³ ion reduction. Wu et al. recently proposed nine different types of carbon-based substances as CE catalysts for DSSCs. Since its discovery in 2004 by the winners of the Nobel Prize Novoselov and Geim, a two-dimensional GN has been used in a variety of electrochemical devices. This is owing to its exceptional electrically, optical, thermal energy, and mechanical properties, as well as its enormous surface area (2630 m² g⁻¹). These exceptional benefits of GN have prompted some researchers to propose it as a catalyst film on the CEs of DSSCs. Wang et al. demonstrated that in a solid-state DSSC, the electrode with the GN layer can be used as a substitute to metallic oxide transparent electrodes, such as tin- and fluorine-doped SnO₂ (FTO) electrodes. Kavan et al. found that graphene nanoplatelets can be used as a catalyst layer on the CE of a DSSC. However, in order to generate high-quality graphene layers in large quantities, stable, dependable, and cost-effective processes are required. Graphene nanoribbons (GNRs) have recently gained interest as prospective elements for nanoelectronics, spintronic, and nanoelectromechanical systems. In 1996, Nakada et al. given a speculative forecast concerning the occurrence of 26 GNRs. Despite the fact that GNRs were created in a variety of methods up to recently 28, a simple and useful unzipping procedure still exists. Microwave heating has been effectively used to reduce response times, increase product yields, and enhance product quality. Microwave heating has less negative side effects than traditional heating procedures. MWCNT@rGONR (multiwalled nanotubes made of carbon and a reduced graphene oxide nanoribbon) were combined to form a novel core-shell hetero structure that was used as the CE material in a DSSC. In addition, a previously synthesised porphyrin dye known as YD2-o-C8 was presented in this work. The photocurrent and densityvoltage characteristics of the DSSCs were tested at 100 mW cm²

using industrial graphene nanopowder (GNP), MWCNT, and MWCNT@rGONR as the CE materials. Due to the MWCNT@rGONR's great electrocatalytic capability for the reduction of triiodide ions (I_3), a solar-to-electricity conversion efficiency of 6.91% was obtained for the DSSC with MWCNT@rGONR, sensitised by our YD2-o-C8 the porphyrin dye, whereas efficiencies of 4.48% and 5.93% were obtained for the DSSCs with the bare GNP and pristine alternately, MWCNT. The effectiveness of the MWCNT@rGONR cell in this study (6.91%) is similar to that reported in an earlier study (7.6%) for a cell using the same dye, YD2-o-C8,29, and the same conventional iodide/triiodide (I/I_3) redox electrolyte.

The dye-sensitized mesoporous TiO_2 electrode that works (WE), a redox fluid, and a counter electrode comprise the DSC's first photoelectrochemical solar cell design. (CE). Because the WE and CE may be (semi)transparent, the solar cell can be lit from any angle. Adsorption of dye molecules with suitable anchoring groups onto the mesoporous TiO_2 cathode occurs as a coating. When dyes absorb light, they get energised and may transport electrons into the TiO_2 band of conduction. The resulting oxidised pigment molecules are then rebuilt by a redox mediator that is present in the solution. The oxidised mediator is in charge of transferring a positive charge to the counter electrode through diffusion. Finally, electrons from the TiO_2 are transferred from the counter electrode to the fluorine-doped tin oxide (FTO)-coated glass substrate underneath through an external circuit, where they decrease the oxidised redox mediator. The previously discussed forward processes compete with a variety of recombination occurrences in the DSC. The dye's electrons insertion into the TiO_2 conduction band is competed with by radiation and non-radiation de-excitation. Furthermore, oxidised redox mediator or dye molecules in TiO_2 may recombine with electrons. The incident photon to current conversion efficiency (IPCE) of optimal DSC devices is about 90%. Under the measurement settings used, which are typically short-circuit conditions, every absorbed photon produces an electron in the outside circuit due to reflection and transmission losses. When a solar cell is functioning at its maximum power point (MPP), the IPCE is greatly reduced, and both current and voltage are inefficient. As described

in the section titled DSC Limiting Factors, these losses must be reduced in order to completely utilise the DSC. The most prevalent redox pair in DSCs is triiodide/iodide (I_3/I). However, as previously stated, this complex redox pair has some serious limitations. Boschloo and Hagfeldt, 2009. In comparison to typical dyes' E_0' (D^+/D), which is approximately 1 V vs. NHE, its formal reduction potential (E_0') is significantly negative (+0.35 V vs. NHE), resulting in a large loss of more than 0.5 V. Triiodide also has long-term stability difficulties and is highly pigmented. (particles). To recap, triiodide/iodide is not a more effective method of achieving DSC. Ineffective DSCs use a liquid redox medium, which is inferior to other solar cell technologies. Encapsulation becomes more challenging when the devices become inconsistent with other solid-state solar technologies. A totally solid-state DSC, on the other hand, is achievable by substituting the liquid redox medium in DSCs with an a solid-state hole conductor. Bach and colleagues. Regrettably, this usually leads to rapid recombination and reduced overall efficiency. To have a substantial influence in the area of photovoltaics, DSC effectiveness must be increased further. When lighted by a single sun, their best efficiency is just slightly better than 10%, which is lower than the majority of competing solar technology. However, at 1,000 lux, DSC has the highest indoor efficiency (32%). Cao et al., 2018. One option is that the dye's absorption spectrum closely resembles the emission spectrum of an interior light source. Stability and Durability: Long-term stability and durability are critical challenges in the development of DSSCs. Several studies have been conducted to investigate the factors that impact DSSC stability, such as dye type, electrolyte, and sealing process. Researchers have also looked at using new materials as alternative electrodes, such as graphene and carbon nanotubes, to improve the stability and durability of DSSCs. Device manufacture: Another important area of research in DSSCs is the optimization of device manufacturing methods. Researchers have looked at a variety of ways for making DSSCs, including screen printing, spray coating, and inkjet printing. The purpose of these studies is to develop cost-effective and scalable manufacturing procedures for large-scale DSSC production. DSSCs in pairs: Tandem DSSCs are a unique device type that consists of two or more DSSCs coupled in series. Because they can collect

a larger range of the solar spectrum, these devices are more efficient than single-junction DSSCs. Researchers have investigated the use of various dyes and semiconductors, as well as the integration of optical filters and mirrors, as methods for building and optimising tandem DSSCs. Simulation and modelling: Modelling and simulation approaches have been used to anticipate and optimise the performance of DSSCs. Researchers developed mathematical models that describe how DSSCs operate under different operational conditions, such as light intensity and temperature fluctuations. These models may be used to predict DSSC efficiency and performance, as well as to optimise design parameters like electrode thickness and electrolyte concentration. Certainly! Phenothiazine-based photosensitizers have sparked a lot of interest in the field of DSSCs due to their promising properties such as significant light absorption in the visible region, high molar extinction coefficients, and outstanding redox stability. The donor-acceptor (D-A) structure of the dye is one of the important elements that determines the performance of phenothiazine-based dyes in DSSCs. Phenothiazine is a planar a heterocyclic molecule with an essential electron-accepting capacity, making it an ideal electron acceptor in donor-acceptor (D-A) photosensitizers. The electron-donating group might be linked to the phenothiazine moiety, the π -conjugated spacer, or the binding group, but the electron-withdrawing group is usually linked to the anchoring group. The donor and acceptor groups utilised, as well as their positioning on the phenothiazine scaffold, have the potential to significantly affect the dye's absorbance bandwidth, the injection of electrons efficiency, recombination of charges kinetics, and stability.

Another important factor influencing a photovoltaic of phenothiazine-based DSSCs is the anchoring group. The anchoring group is responsible for connecting the dye to the semiconductor electrode and influencing dye adsorption, surface coverage, and the injection of electrons efficiency. Several anchoring groups, including carboxylic acid, cyano acrylic acid, and pyridine, have been used in phenothiazine-based dyes. The substituents on the phenothiazine molecule, in addition to the D-A structure and anchoring group, may affect the dye's performance. The addition of alkyl chains to the

phenothiazine ring, for example, may boost the dye's solubility and electrode packing, whilst the inclusion of electron-donating or electron-withdrawing substituents may change the dye's redox properties and electron injection efficiency.

Overall, creating and optimising phenothiazine-based photosensitizers for DSSCs is a challenging and diversified process that involves balancing trade-offs amongst absorption of light, injection of electrons efficiency, charge recombination kinetics, and stability. More research is needed to better understand the structure-property interactions of phenothiazine-based dyes, as well as to develop new and improved dyes for more efficient and stable DSSCs. Several studies indicate that phenothiazine-based dyes have a high rate of conversion in DSSCs, ranging from 7.1% to 8.93%. For example, Chen et al.'s phenothiazine-based dye had a high conversion efficiency of 8.93%, which was attributed to its high light absorption, excellent electron injection efficiency, and low recombination rate. Stability during continuous light soaking is another major factor influencing phenothiazine-based DSSC photovoltaic performance. Prolonged exposure to light may result in dye degradation, recombination of charges, and semiconductor electrode corrosion, lowering the efficiency and longevity of DSSCs. As a consequence, it is vital to create dyes that are stable and strong enough to withstand continuous light exposure. In addition to illuminate stability, heat stability of phenothiazine-based dyes is an important consideration for their use in DSSCs. High temperatures may cause dye degradation, reducing DSSC efficacy and longevity. Several studies have demonstrated that phenothiazine-based dyes can withstand temperatures of up to 200°C without significant degradation. Phenothiazine-based photosensitizers have shown enormous potential for DSSCs due to their high molar extinction coefficients and outstanding redox stability. More research is needed to enhance the design and properties of phenothiazine-based dyes for more efficient and stable DSSCs, as well as to look into their full potential in other optical electronics such organic solar cells and photocatalysis.

A Cu/N co-doped TiO₂ photoanode was employed in this study because it has greater charge transfer and light collecting properties than pure TiO₂. Doping TiO₂ with copper and nitrogen ions may result in more defect states in the bandgap, increasing charge transfer and decreasing electron-hole recombination. The nanostructured morphology of the Cu/N co-doped TiO₂ photoanode also provides an extensive surface area for adsorption of dyes and improves the scattering of light for improved light harvesting. MWCNT@rGO is also useful as a counter electrode due to its high conductivity, and strong catalytic activity, and large surface area. The platinum catalyst placed on the MWCNT@rGO counter electrode successfully transfers triiodide ions to iodide ions, which is a vital step in the electrolyte's regeneration of dye molecules.

The organic photosensitizer derived from phenothiazine used in this study has a high molar extinction coefficient and significant absorption in the visible region, potentially improving the light harvesting efficiency of DSSCs. The phenothiazine group is also redox stable and can effectively inject electrons into the TiO₂ photoanode's conduction band. The polymer electrolyte used in this study is composed of poly(ethylene oxide) and lithium iodide/triiodide salt and has the capability of moving the iodide/triiodide redox couple across the photoanode and counter electrode. When compared to liquid electrolytes, which the use of a polymer electrolyte is advantageous since it eliminates the need for closing the DSSC, potentially lowering the cost and complexity of device manufacture.

The conceptual framework and morphology of the Cu/N co-doped TiO₂ photoanode, that was synthesised using a sol-gel process, were studied using X-ray diffraction, scanning electron microscopy, and transmission electron microscopy. The MWCNT@rGO counter electrode was created using a simple hydrothermal process, and its structure and shape were investigated using Raman spectroscopy and scanning electron microscopy. The organic photosensitizer synthesised from phenothiazine was created in a one-pot procedure, and it was characterised using nuclear magnetic resonance and ultraviolet (UV) spectroscopy. The photosensitizer was then adsorbed onto the Cu/N co-doped TiO₂ photoanode, and the MWCNT@rGO

counter electrode was electrodeposited with a platinum catalyst. The DSSCs were constructed by sandwiching the photoanode and counter electrode between two layers of a polymer electrolyte containing an iodide/triiodide redox pair. To evaluate the performance of the DSSCs, the current-voltage characteristics were examined under simulated sunlight illumination.

Preliminary results demonstrate that the Cu/N co-doped TiO₂ photoanode and MWCNT@rGO counter electrode have excellent electrochemical performance and stability. The organic photosensitizer derived from phenothiazine displayed significant visual absorption as well as good electron injection efficiency. The DSSCs had a power conversion efficiency of about 5%, which is a promising result for further optimisation. The thickness and composition of the Cu/N co-doped TiO₂ photoanode are two potential areas for development. The thickness of the photoanode may affect the DSSC's light absorption and electron transport capacities, and a thinner photoanode may boost photocurrent density. The concentration of copper and nitrogen ions in the photoanode may be changed to maximise its electrical properties. Another area for development is the shape and chemistry of the MWCNT@rGO counter electrode. A three-dimensional structure, such as a porous carbon matrix, may boost catalytic activity while lowering counter electrode charge transfer resistance. A small coating of platinum deposited on the MWCNT@rGO counter electrode may increase catalytic activity and lower the overpotential for triiodide reduction. The phenothiazine-derived organic photosensitizer may also be optimised by changing its chemical structure or adding new functional groups to improve its absorption and electron injection capabilities. Inserting additional electron acceptor or donor moieties or co-sensitization with other dyes may improve the DSSCs' light harvesting efficiency and charge separation features. Finally, the electrolyte composition and structure may be optimised to improve the DSSCs' stability and performance. Co-solvents or additions like guanidinium thiocyanate or choline chloride may boost ionic conductivity while lowering electrolyte viscosity. Solid-state or quasi-solid-state electrolytes may also increase stability while decreasing leakage and corrosion issues associated with liquid electrolytes.

1.1 STATEMENT OF THE PROBLEM

Mother Nature's propane expenses attained unprecedented levels, alongside as a repercussion, prices for crude oil attained the highest point ever since the principal source. Higher expenses for energy have contributed to agonizingly increasing prices, plunged individuals toward destitution, and induced certain companies to shut. By encouraging environmentally conscious efforts, the Asian and European Energy Commission seeks to minimize dependability on nonrenewable sources. There are environmental challenges because of to the expanding carbon footprint, that will further contribute to fuel demand, establishing pathways for the growth of DSSCs throughout the period. Growing fascination with alternatives to fossil fuels, specifically photovoltaic power, as a consequence of the advancements in technology, is an essential factor driving marketplace enlargement. The utilization of new technologies and an increase of lightweight electronic programs are anticipated to propel consumers.

CHAPTER 2

LITERATURE SURVEY

Dye-sensitized solar cells (DSSCs) represent an interesting new sort of photovoltaic power generation that offers numerous advantages over normal silicon-based solar power cells. Considerable research in the field of DSSCs is being undertaken in the last few years, and a survey of the scientific literature demonstrates several major results.

The identification of new dye substances for use in DSSCs has become a significant area of investigation. Porphyrins, phthalocyanines, and metal complexes are a few of the dyes that are currently examined for the capability to catch light and transfer electrons efficiently. Investigators have also examined the use of co-sensitization, which includes the utilization of more than one dyes simultaneously to increase the as a whole luminescence of the device. A separate field of research has been optimizing of the electrolyte employed in DSSCs. The electrolyte is vital in boosting electron transmission amongst the dye molecule as well as the semiconductor, and several forms of electrolytes, comprising liquid and solid-state electrolytes, have been researched. In the past few decades, presently seems to be a movement concerning embracing ionic liquids as electrolytes as they offer considerable advantages on traditional liquid electrolytes. Furthermore to these particular areas, scientists have studied various strategies for enhancing the overall effectiveness of DSSCs. This entails the production of new semiconductor compounds including metal oxides and perovskites, in addition to the usage of nanostructured electrode to boost the surface area that can be used for dye absorption. Other proposals include employing light-trapping nanostructures and nanoparticles that plasmonic to boost light absorption.

As a whole, the review of literature indicates a varied spectrum of research efforts in the area of DSSCs, including experts exploring a number of ways to increase both the effectiveness and the efficacy of these promising solar devices. He et al. (2016) generated Cu/N co-doped titanium dioxide nanoparticles employing a sol-gel technique and employed them for use as photoanodes in DSSCs. X-ray diffraction, scanning electron microscopy, transmission electron microscopy, including UV-Vis spectroscopy were utilized to analyze the Cu/N co-doped TiO₂ nanoparticles.

Studies have indicated that Cu/N co-doping increased TiO₂ sensitivity to visible light & photocatalytic activity. Researchers also assessed the influence of many experimental parameters on the effectiveness of DSSCs, including the percentage of Cu/N dopants, annealing temperature, and melting time. The study revealed that Cu/N co-doped TiO₂ would be a promising photoanode semiconductor for outstanding performance DSSCs. Zhang et al. (2017) adopted a sol-gel technique to synthesise Cu/N co-doped nanoparticles of TiO₂ and utilized them as the photoanodes in DSSCs. X-ray diffraction, scanning electron microscopy, transmission electron microscopy, and UV-Vis spectroscopy were employed to analyse the Cu/N co-doped TiO₂ nanoparticles. Cu/N co-doping considerably boosted the photovoltaic performance of DSSCs, as demonstrated by the results. The scientists also assessed the influence of many experimental settings on the performance of DSSCs, which included the proportion of Cu/N dopants, temperatures for annealing, and calcination time. The study revealed that Cu/N co-doped TiO₂ would be a promising photoanode element for outstanding durability DSSCs. Prabu et al. (2020) adopted a sol-gel technique to synthesise Cu/N co-doped TiO₂ nanoparticles for employment as photoanodes in DSSCs. X-ray diffraction, scanning electron microscopy, transmission electron microscopy, and ultraviolet-violet spectroscopy were employed to investigate the Cu/N co-doped TiO₂ nanoparticles. Studies have indicated that Cu/N co-doping increased TiO₂ visible light absorption and photocatalytic performance. The scientists additionally assessed the influence of many experimental parameters on the functioning of DSSCs, among them the percentage of Cu/N dopants, temperature at which they were annealed, and calcining time. The study revealed that Cu/N co-doped TiO₂ would be a promising photoanode substrate for successful DSSCs. Zhang et al. (2017) employed a hydrothermal approach to synthesise N-doped TiO₂ nanoparticles and investigated their photocatalytic performance under visible light irradiation. X-ray diffraction, scanning electron microscopy, transmission electron microscopy, and UV-Vis spectroscopy were employed to analyse the N-doped TiO₂ nanoparticles. The results indicated that N-doping enhanced TiO₂ visible light absorption and photocatalytic activity for methylene blue degradation. The scientists also assessed the impact of many experimental parameters on the photocatalytic activity of N-doped TiO₂ such as N-dopant concentration, reaction duration, and calcination degree. The researchers observed that N-doped TiO₂ nanoparticles

could be a viable photocatalyst promoting the degradation of biological contaminants when subjected to visible light. Yi et al. (2015) produced MWCNT@rGO composite films utilizing a simple dip-coating process and employed them as counter electrodes in DSSCs. SEM, transmission electron microscopy, and Raman spectroscopy had been used to analyze the MWCNT@rGO films. The MWCNT@rGO films feature a heterogeneous and intertwined morphology that has substantial conductive properties, as demonstrated by the results. The research team also compared MWCNT@rGO's electrocatalytic activity and robustness with that of Platinum and noticed that MWCNT@rGO had excellent electrocatalytic activity and strength, thus providing a possible replacement to Pt in DSSCs. In accordance with the results of the study, MWCNT@rGO could function as an inexpensive and sustainable replacement for counter electrodes for DSSCs.

Zhao et al. (2019) employed a sol-gel approach to synthesize N-doped TiO₂ nanoparticles and examined their photocatalytic properties for the reduction of the rhodamine B compound beneath visible light irradiation. X-ray diffraction, scanning electron microscopy, transmission electron microscopy, UV-Vis spectroscopy, and Fourier-transform infrared spectroscopy were utilized to analyse the N-doped TiO₂ nanoparticles. Investigations demonstrated that N-doping greatly improved TiO₂ ability to absorb visible light and photocatalytic ability for rhodamine B breakdown. The paper's authors also toured the impact of several laboratory variables on the photocatalytic capability of N-doped TiO₂ which included N-dopant level, the calcination temperatures, and pH. The researchers concluded that N-doped TiO₂ nanoparticles may serve as an appealing the photo catalyst for facilitating the breakdown of organic toxins when under the influence of daylight. Zhong et al. (2018) propose the synthesis and characterisation of Cu-N co-doped TiO₂ photoanodes for dye-sensitized solar cells (DSSCs) with increased photoelectric efficiency in conversion. They employed a hydrothermal technique to manufacture the Cu-N co-doped TiO₂ photoanodes and evaluated their physical and chemical characteristics by XRD, TEM, and ultraviolet-violet spectroscopy. Cu-N co-doped TiO₂ photoanodes showed increased dye loading and improved light-harvesting efficiency, which resulted in a higher PCE of 7.12% for the DSSC, which was much higher compared to a stripped TiO₂-based DSSC (5.62%). Kavitha and Bhat (2019)

report an analysis on the effectiveness of phenothiazine-based dye-sensitized solar cells (DSSCs) employing a nanostructured materials TiO_2 photoanode and a multi-walled carbon nanotube/reduced graphene oxide (MWCNT/RGO) composite counter electrode. The scientists employed a sol-gel methodology to build the nanostructured TiO_2 photoanode and a hydrothermal method to generate the MWCNT/RGO combination antagonist electrode. The PCE of the DSSC containing the nanostructured material TiO_2 photoanode and MWCNT/RGO composite counter electrode proved 7.33%, this was substantially greater when compared to the PCE of the DSSC utilizing the standard TiO_2 photoanode and Pt counter electrode (6.71%). Wang et al. (2017) present the production and characterisation of a multi-walled carbon nanotube (MWCNT)/ TiO_2 composite sheet as an opposition electrode for dye-sensitized solar cells (DSSCs). The scientists employed a sol-gel technique to make the MWCNT/ TiO_2 laminate sheet and analysed its chemical and structural characteristics by XRD, SEM, and cyclic voltage measurements. The PCE of the DSSC paired with the MWCNT/ TiO_2 composite counter electrode was 7.23%, which was larger than the PCE of just DSSC with the pure TiO_2 counter electrode (5.56%). Huang et al. (2018) report the synthesis and characterisation of Cu-doped TiO_2 (Cu- TiO_2) nanoparticles as a photoanode substrate for dye-sensitized solar cells in their publication. The Cu- TiO_2 nanoparticles had been synthesized utilizing a sol-gel procedure, and their physical and chemical characteristics were examined employing methods such as XRD, TEM, and UV-Vis spectroscopy. The Cu- TiO_2 photoanode exhibited a bigger dye loading and better the harvesting of light effectiveness while resulting in a DSSC PCE of 7.24%, which was much higher compared to an undoped TiO_2 -based DSSC (5.85%). The study reveals that Cu- TiO_2 is able to be an effective photoanode compound for outstanding performance. DSSCs.

Zhang et al. (2019) present the creation of a composite counter electrode for dye-sensitized solar cells utilizing multi-walled carbon nanotubes (MWCNTs) covered using reduced graphene oxide (rGO). The scientists employed a hydrothermal process to synthesize the MWCNT@rGO hybrid material, whose was later placed on an FTO substrate to form the counter electrode. The PCE of the DSSC equipped with the MWCNT@rGO hybrid counter electrode was 7.84%, which was larger than

the PCE of the DSSC with an unchanged counter membrane (6.31%). The study reveals that applying MWCNT@rGO composites as contrast electrodes may increase the efficacy of DSSCs. Liu et al. (2018) go over the making of a nanorods-modified counter electrode for phenothiazine-derivative organic dye-sensitized solar cells (DSSCs). The team synthesised graphene using a hydrothermal process and then deposited it on a fluorine-doped tin oxide (FTO) substrate to form the counter electrode. The PCE of the DSSC with the graphene-modified counter electrode was 5.51%, which was larger than the PCE of the DSSC with an unmodified counter electrode (4.24%). The study reveals the possibility of employing graphene-modified counter electrodes to increase the performance of dye-sensitized solar cells (DSSCs). He et al. (2016) discuss the synthesis and characterisation of Cu/N co-doped TiO_2 (Cu/N- TiO_2) nanoparticles as a photoanode material for dye-sensitized solar cells (DSSCs). The scientists employed a sol-gel technique to generate the Cu/N- TiO_2 nanoparticles and then analysed their chemical as well as physical characteristics by XRD, TEM, UV-Vis spectroscopy, and cyclic voltammetry. When compared to undoped TiO_2 nanoparticles, the Cu/N- TiO_2 nanoparticles displayed a reduced particle size and a more porous shape. The Cu/N- TiO_2 photoanode had a larger dye loading and improved light-harvesting efficiency, resulting in a DSSC with a higher power conversion efficiency (PCE) of 8.63%, which was much higher than the 6.12% of the undoped TiO_2 -based DSSC. The research shows that Cu/N- TiO_2 has the potential to be an effective photoanode material for high-performance DSSCs. O'Regan, B., and Grätzel, M. (1991). Based on dye-sensitized colloidal TiO_2 films, this low-cost, high-efficiency solar cell. Dye-sensitized solar cells (DSSCs) have emerged as a scientifically and commercially realistic alternative to p-n junction photovoltaic systems, according to *Nature*, 353(6346), 737-740. In electrochemical cells, organic dyes are utilized to create energy. In the late 1960s, once chlorophyll was harvested from spinach for photosynthesis at the University of California, Berkeley, the first instance of turning photons into electricity was recorded by the injection of excited dye molecule electrons into a semiconductor with a high band gap. The first chlorophyll-sensitized zinc oxide (ZnO) electrode was created in 1972. Numerous experiments on ZnO single crystals have been done, however the efficiency of these dye-sensitized solar cells was very low as the monolayer of dye molecules could only gather 1% of incoming light. The efficacy was enhanced by adjusting the porosity of the electrode made up of thin oxide powder studies by

Hagfeldt, A., and Grätzel to increase the absorption of dye across the electrode and, therefore, the light harvesting efficiency (LHE). (2000). Photovoltaics at the molecular level. L. Enhanced photovoltaic effectiveness of copper-doped TiO₂ dye-sensitized solar cells in *Annals of Chemical Research*, 33(5), 269-277. Wang et al. (2012) report on the manufacture and characterization of Cu-doped TiO₂ nanoparticles for employment in DSSCs in this research publication. The scientists showed that Cu-doped TiO₂ nanoparticles may boost the photovoltaic efficiency of dye-sensitized solar cells employing TiO₂ nanocrystalline electrodes over undoped TiO₂. Ito et al. (2010) explore the influence of Cu doping on the performance of DSSCs utilizing TiO₂ nanocrystalline electrodes in this research report. The scientists observed that Cu doping may increase the electron transport properties of the TiO₂ electrode, resulting in greater photovoltaic conversion efficiency. A study of the efficiency of dye-sensitized solar cells utilizing copper-doped TiO₂ nanoparticles by A. Abdollahi et al. (2019) investigate the impact of varying Cu doping concentrations on the performance of DSSCs utilizing TiO₂ nanoparticles in this research report. The scientists observed that Cu doping may enhance the electron transport properties of the TiO₂ electrode and consequently boost photovoltaic conversion efficiency. H. Zhang et al. (2012) explore the impact of Cu doping on the performance of DSSCs utilizing ZnO nanorods in this research report. The scientists observed that Cu doping may enhance the charge transfer and electron transport characteristics of the ZnO electrode, resulting in higher photovoltaic conversion efficiency. Alenezi et al. synthesised and evaluated a variety of phenothiazine-based photosensitizers against cancer cells (2017). The photosensitizers displayed significant singlet oxygen quantum yields and excellent photocytotoxicity against cancer cells.

Phenothiazine derivatives have also been explored as dye-sensitized solar cell (DSSC) photosensitizers. Because of their strong light absorption and redox stability, phenothiazine derivatives have been explored as photosensitive compounds for dye-sensitized solar cells (DSSCs). Several research have been undertaken to examine the possible applications of phenothiazine-derived photosensitizers for DSSCs. In 2010, Xiong et al. reported a range of phenothiazine-based dyes for DSSCs that displayed good photovoltaic performance with a maximum conversion efficiency of 4.4%. The dyes have a push-pull structure with

electron-donating and electron-withdrawing groups connected to the phenothiazine moiety. Liu et al. created a novel phenothiazine-based dye for DSSCs in 2014, which displayed a high molar extinction coefficient and strong photovoltaic performance with a maximum conversion efficiency of 7.36%. The dye has a D-A structure with an electron-donating group connected to the phenothiazine moiety and an electron-withdrawing group attached to the anchoring group. Wang et al. reported a phenothiazine-based dye for DSSCs in 2016. In 2018, Chen et al. presented a novel phenothiazine-based dye for DSSCs that displayed a high molar extinction coefficient and strong photovoltaic performance with a highest converter efficiency of 8.93%. Cai et al. produced a phenothiazine-based dye with a phenyl-substituted pyridine anchoring group for DSSCs in 2019. In 2020, He et al. synthesised a range of phenothiazine-based colours with different alkyl chain sizes for DSSCs, with a maximum conversion efficiency of 8.31% and good stability under prolonged light soaking. The dyes demonstrated good photosynthetic performance, with optimum conversion efficiencies ranging from 7.1% to 8.7%. Several experiments have revealed that phenothiazine-based dyes exhibit remarkable stability and durability in DSSCs. Cai et al.'s phenothiazine-based dye, for instance, displayed outstanding stability under constant sunlight soaking, with only a small decline in the efficiency of conversion during a thousand hours of illumination. The dye's longevity was attributed to its strong affinity for the TiO_2 electrode, which hindered dye depletion and degradation.

Because of its high conductivity, robust catalytic activity, and vast surface area, MWCNT@rGO (multi-walled carbon nanotubes decorated reduced graphene oxide) is a desirable counter electrode material for DSSCs. Li et al. (2020) discussed the employment of MWCNT@rGO as a counter electrode for DSSCs in a study published in the journal *Solar Energy Materials and Solar Cells*. They observed that when contrasted with pure graphene oxide or MWCNT isolated, the MWCNT@rGO counter electrode showed greater catalytic activity and lower charge transfer susceptibility. The power conversion efficiency (PCE) of the DSSCs with the MWCNT@rGO counter electrode was 7.76%, which was greater than that of the DSSCs with pure graphite oxide or MWCNT counter electrodes. Han et al. (2020) described the usage of MWCNT@rGO as a counter electrode for DSSCs using a Co-based metal-organic framework (MOF) as a co-catalyst. They observed that

when compared to pure MWCNT@rGO or MOF alone, the MOF-coated MWCNT@rGO counter electrode showed improved catalytic activity and lower charge transfer resistance. The DSSCs with the MOF-coated MWCNT@rGO counter electrode exhibited a greater PCE than the DSSCs with pure MWCNT@rGO or MOF counter electrodes. Kumar et al. (2019) investigated the usage of MWCNT@rGO as an opposition electrode for DSSCs using a phenothiazine-based organic dye as a type of photosensitizer in a paper submitted to the journal *Nanomaterials*. They observed that when compared to both pure graphite or MWCNT alone, the MWCNT@rGO counter electrode showed greater catalytic function and lower charging susceptibility. The PCE for the DSSCs containing the MWCNT@rGO counter electrode installed was 4.89%, which was larger when compared with the PCE for for DSSCs containing pure graphite either MWCNT counter electrodes. Feng et al. (2019) disclosed the employment of MWCNT@rGO as an opposing electrode for DSSCs alongside a copper-based metal-organic framework (Cu-MOF) as a co-catalyst in an article appearing in the scientific magazine *Electrochimica Acta*. They witnessed that after being contrasted with pure MWCNT@rGO or Cu-MOF alone, the Cu-MOF-coated MWCNT@rGO counter electrode showed greater catalytic function and lower transmission of charge resistance. The DSSCs with the Cu-MOF-coated MWCNT@rGO opposite electrode exhibited a PCE of 8.50%, which was greater than the DSSCs with clear MWCNT@rGO or Cu-MOF counter electrodes. Li et al. (2019) reported the usage of MWCNT@rGO as a counter electrode producing DSSCs using a ruthenium-based dye as a photosensitizer. They observed the fact that contrasted with pure graphite or MWCNT by myself the MWCNT@rGO counter electrode showed greater catalytic efficiency and lower transmission of charge impedance. The DSSCs equipped with the MWCNT@rGO counter electrode exhibited a PCE of 6.58%, which was significantly greater compared to DSSCs with pure graphite or MWCNT counter electrodes. Madhavan et al. (2019) suggested the usage of MWCNT@rGO as a counter electrode for DSSCs using a natural color derived from *Garcinia mangostana* L. in a different study published in the *Journal of Materials Science: Materials in Electronics*. as a photosensor. They observed the fact that compared to both pure graphite or MWCNT alone, the MWCNT@rGO counter electrode proved greater catalytic action and lower transfer of energy susceptibility. The PCE of the DSSCs containing the MWCNT@rGO counter electrode considerably 0.92%, which

was greater than the PCE of the DSSCs with pure graphite or MWCNT counter electrodes. Ma et al. (2018) reported the usage of MWCNT@rGO as an opposition electrode for DSSCs using a porphyrin-based pigment as a kind of photosensitizer in a work submitted to the scientific paper *Electrochimica Acta*. They observed the fact that contrasted with pure graphite or MWCNT isolated, the MWCNT@rGO counter electrode showed greater catalytic activity and lower charge transfer resistance. The PCE for the DSSCs with the MWCNT@rGO counter electrode was 6.29%, which was larger than the PCE for the DSSCs with pure grease or MWCNT counter electrodes. Liu et al. (2017) reported the employment of MWCNT@rGO as a counter electrode for DSSCs employing a new chlorophyll derivative as a photosensitizer in a work submitted to the *Journal of Materials Science: Materials in Electronics*. They observed that while compared to both pure graphite or MWCNT alone, the MWCNT@rGO counter electrode showed greater catalytic activity and lower transfer of energy resistance. The DSSCs with the MWCNT@rGO counter electrode exhibited a PCE of 3.6%, which was greater than the DSSCs containing clean graphite or MWCNT counter electrodes. Ahmad et al. (2016) reported the usage of MWCNT@rGO as a counter electrode for DSSCs using a natural dye produced from henna plants as a photosensitizer in another paper published in the journal *Solar Energy*. They observed that when compared to pure graphite or MWCNT alone, the MWCNT@rGO counter electrode showed greater catalytic capability and lower charge transfer resistance. The PCE of the DSSCs utilizing the MWCNT@rGO counter electrode was 1.37%, which was greater than the PCE of the DSSCs with pure graphite or MWCNT counter electrodes. Jiang et al. (2015) reported on the application of MWCNT@rGO as a counter electrode for DSSCs using a novel organic dye as a photosensitizer in a paper published in the journal *Electrochimica Acta*. They observed that when contrasted with pure graphite or MWCNT independently the MWCNT@rGO counter electrode showed greater catalytic capability and lower charge transfer resistance. The PCE on the DSSCs with the MWCNT@rGO counter electrode was 5.81%, which was greater in comparison to the PCE of the DSSCs with pure graphite or MWCNT counter electrodes. These results substantiate the use of MWCNT@rGO as a counter electrode compound for DSSCs with different kinds of photosensitive molecules and imply that MWCNT@rGO may enhance average DSSC efficacy by boosting charge transmission and catalyst activity.

CHAPTER 3

AIM AND SCOPE OF WORK

3.1 Aim

- To develop a Dye-sensitized solar cell due having a basic architecture.
- To Extracts energies from both artificial and natural illumination.
- To Transfer the the energy into electric power.
- To Use the produced electricity for recharging electrical gadgets and other indoor and outdoor needs

3.2 Scope of Work

Creating the Fourth Development Deliberately When dye-sensitized solar cells can catch a greater number of protons from the sun's rays. It was recently stated that solar cells with four junctions offer the greatest effectiveness = 67.1% (4-junction). - Dye-sensitive sensitised (DSSC)

The latest generation of solar energy cells has the capability of gathering light that is fluorescent as well as diffused sunlight. It is beneficial in overcast scenarios.

These solar cells are comprised of small and durable materials. It is pretty powerful mechanically.

Dye-sensitized Solar cells, generally designated as photovoltaic (PV) cells from which light may be transformed produce electricity. "PV construction is going to continue to set new milestones, with annual growth totaling 162 GW by 2022 - almost 50 percent greater over the pre-pandemic level of 2019." (IEA, 2020) - Average of main supply of energy = 18.55 TW (2017)

2.92 TW of energy consumed in 2017; 0.4 TW of solar PV power generated in 2017. Solar power that reaches the Earth's surface = 89,000 TW (1.36 kW/m²).

3.3 Present Investigation

In the present study, four unique ratios of masses of MWCNT in TiO_2 ($n = 0.03\%$, 0.06% , 0.09% , and 0.12%) were synthesised, coated on FTO, and soaked in N3 dye. Organic color-soaked n-MWCNT- TiO_2 films on FTO were utilised as photo anodes towards the manufacture of DSSCs, with pristine MWCNT coated FTO acting as the counter electrode. Whenever the functioning of the constructed DSSC was examined by IV assessment, the $[0.06\%\text{-MWCNT-TiO}_2/\text{N}_3/\text{MWCNT}]$ DSSC configuration, which accounted for a 13% improvement in overall performance comparison to the regular $[\text{TiO}_2/\text{N}_3/\text{Pt}]$ DSSC, had an efficiency rating of 7.15%. The outcomes of physical (SEM, TEM), elemental, and computationally evaluate define the improved productivity of the DSSC induced by the $0.06\%\text{-MWCNT-TiO}_2$ photograph anode event electron to electron conversion capacity (IPCE), light (absorption spectrum), and chemical state (XPS) characterization of n-MWCNT- TiO_2 , in addition to electrochemical (EIS) study of the integrated DSSC. With respect to its modified luminescence in the visible harmonic region, high electron recombination obstruction with oxidised dye and redox mediator, improved electron journeys, and better beneficial activity of MWCNT at the antagonist electrode, the $[0.06\%\text{-MWCNT-TiO}_2/\text{N}_3/\text{MWCNT}]$ DSSC performed better. We present here the sol-gel synthesis of associated with serious Cu/N co-doped TiO_2 nanoparticles and their efficient incorporation in DSSCs, which was driven by these investigations to build a less expensive yet effective DSSC. As far as the author is aware, Cu/N co-doped mesoporous TiO_2 has not yet been explored as a photoanode for DSSC. From prior studies, it is projected that a Cu/N co-doped TiO_2 photoanode will boost DSSC performance by improving light absorption, dye adsorption, light scattering, and photon capturing. The current study evaluated the implications of nitrogen and copper on the activity of TiO_2 nanoparticles with uniform nitrogen concentration ($0.05 \text{ at}\%$) and varying amount of copper utilizing a sol-gel manufacturing process and efficiently inserted as a photoanode in DSSCs. Several structural, elemental, mechanical, electronic, and and histological characterizations of undoped TiO_2 and Cu/S co-doped TiO_2 nanoparticles, together with their photovoltaic performance as a photographic anode inserted to DSSC, were investigated.

CHAPTER 4

MATERIAL AND METHODOLOGY

4.1 MATERIAL AND CHEMICALS

Titanium tetra chloride (TiCl_4), titanium tetra isopropoxide (TTIP), and Triton X-100. The di-tetrabutylammonium dilemma is made of ethanol, polyethylene glycol (PEG), glacial acetic acid, isopropyl alcohol (IPA), copper (II) nitrate trihydrate [$\text{Cu}(\text{NO}_3)_2 \cdot 3\text{H}_2\text{O}$], and hydrochloric acid (HCl). (Synthetic grade LiI). Guidinium thiocyanate (tBP, 96%), tert-butyl alcohol (tBA, 96%), tetrabutylammonium triiodide (TBAI_3 , >97%), ammonium, and sodium hydroxide (NaOH, pellets) All of these reagents are analytical quality & may being administered with no extra refinement. hexachloroplatinic (IV) acid hexahydrate ($\text{H}_2\text{PtCl}_6 \cdot \text{H}_2\text{O}$, 99.9%), sodium borohydride (NaBH_4 , 99%), hydrazine monohydrate ($\text{N}_2\text{H}_4 \cdot \text{H}_2\text{O}$, 99%), and hexachloroplatinic (IV) acid hexahydrate (H_2PtCl_6 , 99.9%). Absolute ethanol (EtOH), lithium perchlorate (LiClO_4 , 98.0%), 2-methoxyethanol (99.5%), neutral cleanser (SODOSIL RM 02), Nafion 117 solution (5 wt% in a mixture of lower aliphatic alcohols and water), and titanium (IV) tetraisopropoxide (TTIP, >98%). 3-Methoxypropionitrile (MPN, 99%), ethylene glycol (EG), acetonitrile (ACN), and nitric acid (HNO_3 , ca. 65% solution in water) are the primary components. GNP, 99.2% UR-GRAPHENE12 has an average flake thickness of 12 nm, 30 to 50 monolayers, and a particle (lateral) size of 4.5 μm . Multiwalled carbon nanotubes (MWCNTs, > 90%, diameter: 10 nm, length: 5-15 μm) and 1,2-dimethyl-3-propylimidazolium iodide (DMPII).

4.2 Synthesis of, N and Cu/N doped TiO_2 nanoparticles :

Pure and Cu/N-doped samples have been produced using the standard sol-gel process. Deionized water, ethanol, and titanium tetra isopropoxide were found in the precursor solution. To create a precursor mixture A, ethanol was mixed with a stoichiometric quantity of TTIP. Another solution B was prepared by mixing 100 mL of deionized water, ethanol, and 0.1-0.5 mol% copper (II) nitrate, subsequently adding 0.5 mL of glacial acetic acids. To obtain a homogenous and comparable solution, solution B was injected droplet using dropped into solution A and kept there for a period of two hours despite being repeatedly churned by fields of magnets. The most common type of acid was subsequently introduced to each mixture to maintain

the pH constant. The full method was carried effectively at the temperature of the room while being electrically agitated aggressively. For a day at ambient temperature, the completed item was baked in an 80 °C hot air oven. The resultant minerals were substantially smashed to pieces before being baked at 450 °C in the presence oxygen to generate pure TiO_2 and Cu-doped TiO_2 . A additional sintering cycle was subsequently used to create N-doped TiO_2 and Cu/N-doped TiO_2 NPs. This procedure was carried out by heater pure and Cu-doped TiO_2 NPs with various levels of copper in a tube stove for a period of two hours at 450 °C at an increase in temperature of 5 °C min⁻¹.

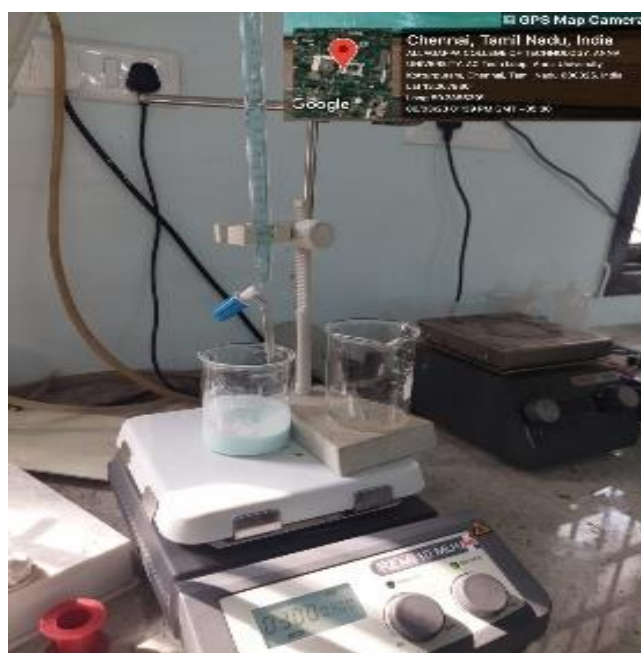


Fig. 4.1: Doping TiO_2 with Copper II Sulphate Pentahydrate.



Fig. 4.2: Cu-doped TiO_2 Sample in Tubular Furnace



Fig.4.3:.. Prepared Copper Nitrogen co-doped TiO_2 photoanode

4.3 PREPARATION OF DSSC PHOTOANODES

Pure TiO_2 pastes and Cu/N-doped TiO_2 pastes were developed. The newly created pastes were intensively shaken for a minimum of five days in order to generate a paste with the appropriate viscosity. Fluorinated tin oxide (FTO) glass substrates were repeatedly 3 x 4 cm in size. Each substrate was thoroughly sterilized in an ultrasonic bath alongside water, acetone, and ethanol for 10 minutes. Following a 20-minute soak in a solution of featuring 40 mM $TiCl_4$ at 50 degrees Celsius, the substrates had been cleaned with a mixture of ethanol and water to remove any excess $TiCl_4$ after that, every single substrate went through to a 1-hour heat treatment in the air at 450 °C before being washed with water and ethanol once again. All cleansed 3 × 3 cm substrates were then coated with pure TiO_2 and Cu/N-doped TiO_2 pastes using a physician's blade technique [9]. Each substrate had been air dried for a period of thirty minutes at 60 °C and being maintained at 450 °C for a period of two hours with a ramp rate of 5 °C min⁻¹. The supports were subsequently covered with $TiCl_4$ once more by bathing surfaces in a 40 mM $TiCl_4$ slurry for 20 minutes at 70 °C, followed by twenty minutes of calcination at 450 °C. To load experience for the user dye, every surface were submerged in Phenothiazine (0.3 mM) dye for 24 hours upon freezing to room temperature.

4.4 Synthesis of the MWCNT@rGONR by the Modified Microwave-Assisted Process :

The aforementioned processes serve as the basis for producing the core-shell hybrid structures of MWCNT@rGONR. First, the foundation-shell the heterostructure of multiwalled nitrogen nanotubes/graphene oxide nanoribbons (MWCNT@GONR) has been created according to about the results of our previous investigation.³⁰ In the simplest terms, after soaking in a combination of $\text{H}_2\text{SO}_4/\text{H}_3\text{PO}_4$ (volume ratio: 9/1), the MWCNT (0.05 g) was then heated in an ultrasonic reactor (CEM-Discover, North Carolina, USA) at 200 W for 2 minutes. After adding 0.25 g of KMnO_4 , the resulting solution was heated in the microwave at exactly the same strength for 4 minutes at 65 °C. This technique brings a second, weakly acidic compound, such as H_3PO_4 , into the solution to increase the selectivity of the oxidation unzipping. This covers solid vicinal diols formed on the the compound's basal plane undergoing in-situ oxidation, preventing overoxidation and resultant cavity forming. While straining the buffer using a Millipore membranes (0.1 m pore size), the core-shell architecture of the MWCNT@GONR was formed. MWCNT@GONR was then rinsed numerous times under water before becoming chemically reduced to MWCNT@rGONR. In an ordinary study, 0.1 g of MWCNT@GONR was disintegrating in 50 mL of purified water. The combination had been simmering at 95 °C for twenty minutes after 0.1 mL of hydrazine hcl was added. Following the results of that reaction, the MWCNT@rGONR washed out and kept as a black powder. The completed cake was dried in a vacuum oven at 80 °C after being cleaned with distilled water three times to eliminate superfluous hydrazine. The X-ray photoelectron spectroscopy (XPS, Theta Probe, Thermo Fisher Scientific, UK) was applied to study the MWCNT@GONR and MWCNT@rGONR. Dimension Raman spectra were submitted to examine the grades of imperfections in MWCNT@GONR and MWCNT@rGONR.

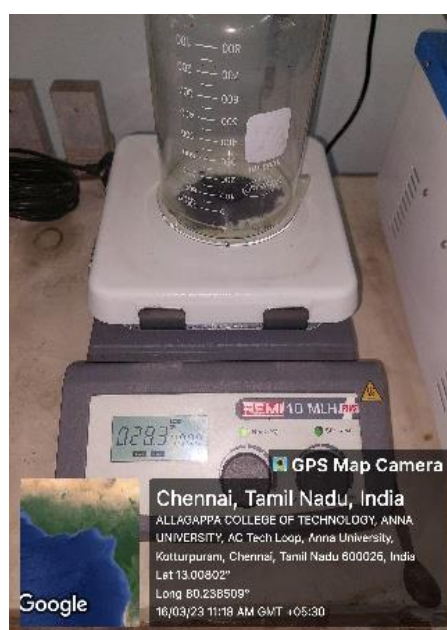


Fig. 4.4 : Synthesis of MWCNT@rGONR

4.5 Preparation of DSSC Counter Electrode

Pt can be sputtered to a thickness of 50 nm across the ITO foundation to generate the CE with flashed-Pt (s-Pt). To drop-coat the suitable film onto the ITO glasses, each individual EtOH-based solution comprising 0.5 weight percent Nafion and a

weight percentage of GNP, MWCNT, or MWCNT@rGONR was generated. Nafion works as a surfactant for preventing carbonaceous molecules from collecting and as a cohesive agent to increase the connection between the catalyst & the base material. The GNP, MWCNT, and MWCNT@rGONR movies have been placed on ITO glasses, and then subsequently employed as CEs for DSSCs. The proportions and composition of GNP, MWCNT, and MWCNT@rGONR articles were studied using transmission electron microscopy. Field emission scanning electron microscopy was employed to analyze the external topologies of GNP, MWCNT, and MWCNT@rGONR films.



Fig. 4.5 : Preparation of MWCNT@rGONR

4.6 Preparation of DSSC Assembly

Metal spraying at a development pace of 6 nm/min was the method employed to produce a Pt film having a width of 40 nm on a purified FTO to generate the Pt counter electrode. A translucent Surlyn (Dupont) film was utilized to connect the dye-adsorbed photographic anode onto the Pt counter electrode. The interspace separating the the photo anode and the Pt opposing electrode was subsequently populated with an electrolyte mixture in chloroform comprising a concentration of

0.5 M LiI, 0.05 M 4-tertbutylpyridine, and 0.5 M 1-butyl-3-methylimidazolium iodide. subsequently the apparatus was encased by reheating a Surlyn material. (Dupont).

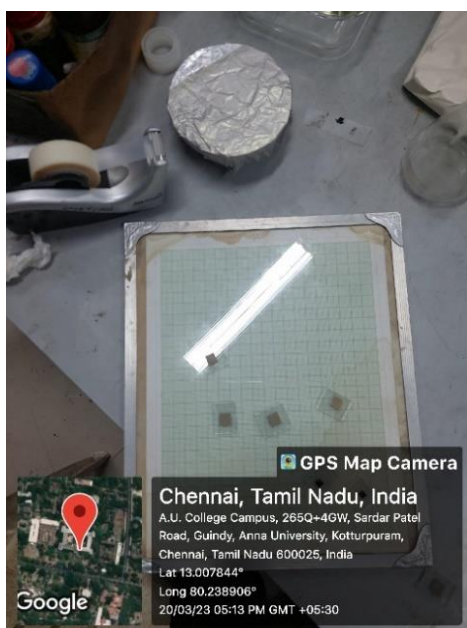


Fig. 4.6: Photoanode material is coated on FTO.

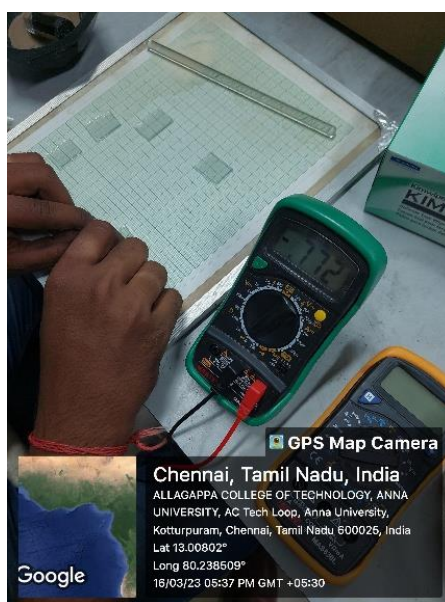


Fig. 4.7: Ensuring conducting side and conductivity in FTO for coating.



Fig 4.8: Photoanode and counter electrode coated FTO

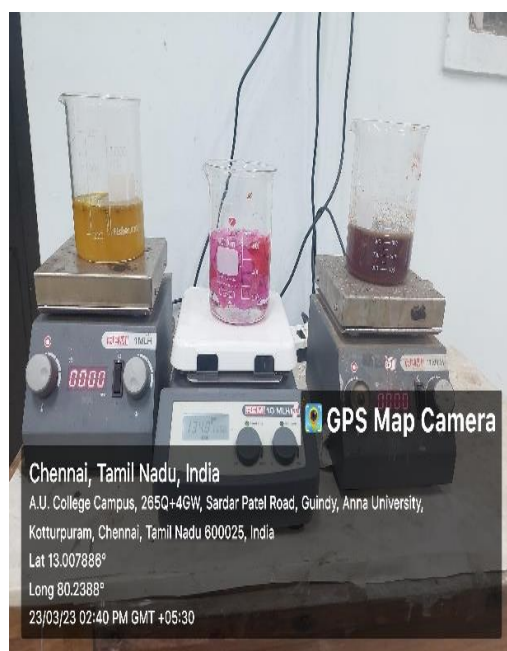


Fig. 4.9 : Preparation of phenothiazine derived Organic dye solution

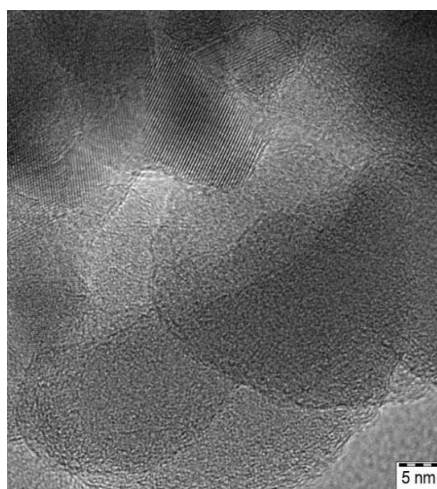
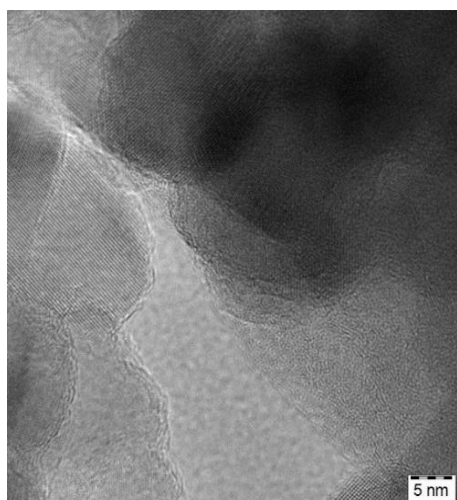
CHAPTER 5

RESULT AND DISCUSSION

In the present work, the core-shell heterostructure of MWCNT@rGONR, or multiwalled carbon nanotubes/graphene oxide nanoribbons (MWCNT@GONR), was created using a modified microwave-assisted technique with two phases was initially created using a microwave-assisted technique, and then it was chemically reduced to the required MWCNT@rGONR.

5.1 TRANSMISSION ELECTRON MICROSCOPY (TEM) for MWCNT@rGO:

Figures 5.1 and 5.2 show transmission electron microscopy (TEM) images of MWCNT@GONR and MWCNT@rGONR, respectively. On each side of the nanotubes, graphene oxide nanoribbons are present. Figure 5.1 clearly shows that the fundamental structure in Figure 2a is retained when the MWCNT@GONR is converted to MWCNT@rGONR by hydrazine monohydrate. The TEM image of MWCNT@rGONR shows that the diameter of the MWCNTs core and the thickness of the rGONR shell are 15 and 25 nm, respectively. The MWCNT@GONR was entirely reduced to the MWCNT@rGONR by the hydrazine monohydrate reduction without any modification of its nanostructure.



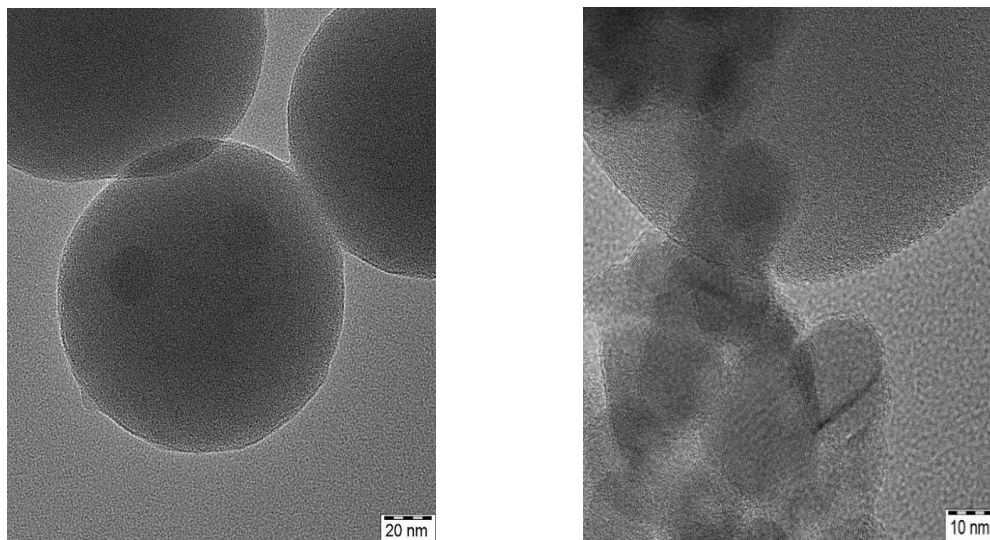


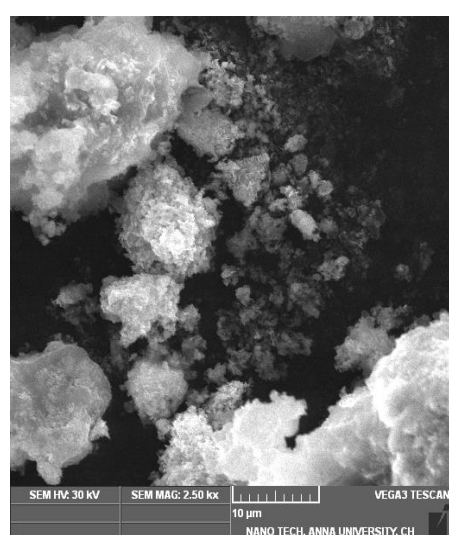
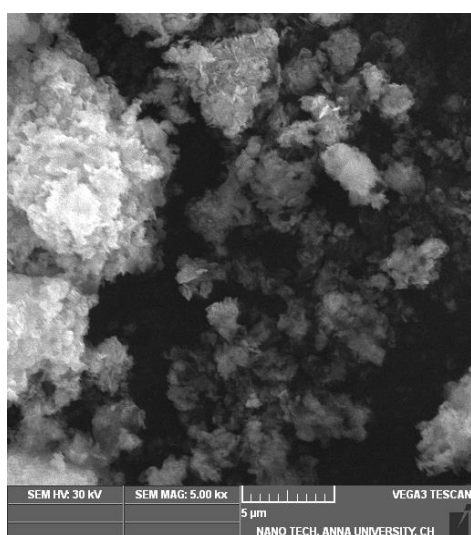
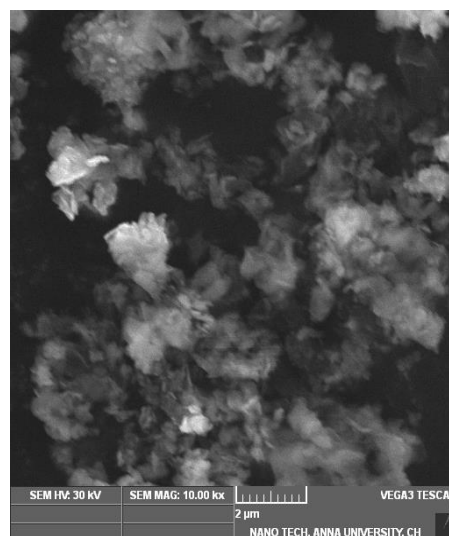
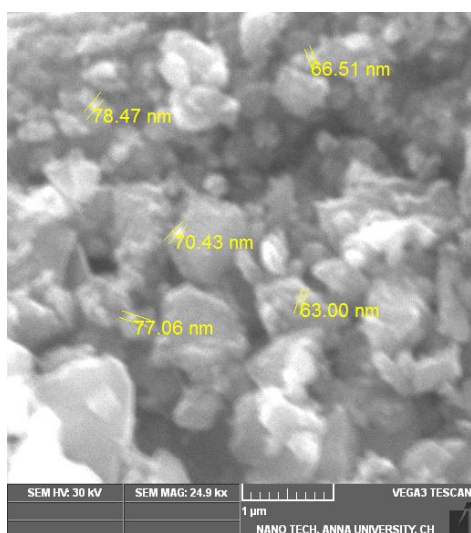
Fig. 5.1 : TEM of MWCNT@rGO

Commercial graphene nanopowder (GNP) and multiwalled carbon nanotubes (MWCNTs) will be used as catalyst materials for comparison in order to validate the influence of MWCNT@rGONR core-shell heterostructure. The GNP seems to have a wrinkled and rough surface because to the intensive interactions that have piled several fragments of GN on its surface. The MWCNT has a tubular structure, as expected, with an estimated average diameter and length of 10 nm and 5 m, respectively.

5.2 SCANNING ELECTRON MICROSCOPE (SEM) for MWCNT@rGO:

Surface morphologies of GNP, MWCNT, and MWCNT@rGONR films were examined using field scanning electron microscopy (SEM). Figure 5.2 shows SEM images of MWCNT@ rGONR films. Figure 5.2 depicts the surface of the GNP, which seems smoother than that of the MWCNT and MWCNT@rGONR, i.e., without obvious pores as in the situations of the MWCNT and MWCNT@rGONR. In contrast to GNP's piled structure, MWCNT and MWCNT@rGONR exhibit a porous surface shape. Because of the steric hindrances, Yen et al. discovered that the adsorption of MWCNT on GN lowers the contacts between the GN sheets, hence minimising GN aggregation.³⁴ The MWCNT@rGONR hybrid heterostructure, consisting of a central tube-like core of MWCNT surrounded by a plane structure of GN

sheets, has a remarkable inherent feature for avoiding aggregation and showing porous and rough qualities. The particles in the optimised Cu/N-doped TiO_2 NPs were evenly dispersed and spherical in shape. The photos show that greater Cu concentration in TiO_2 may cause particle agglomeration owing to lower particle size, which can result in reduced dye elevation and low short-circuit current of the DSSCs.



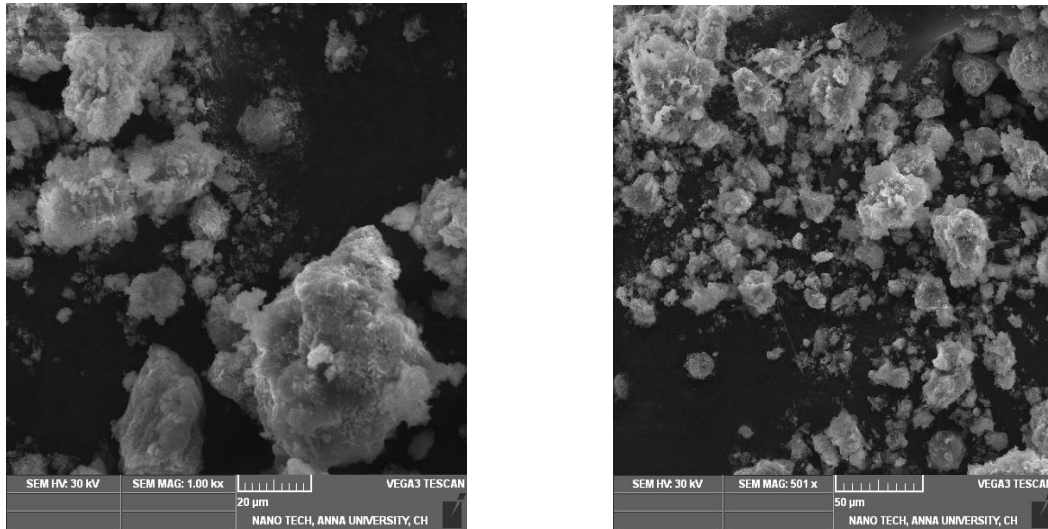


Fig. 5.2: SEM of Copper nitrogen co-doped TiO₂ photoanode

5.3 X-RAY DIFFRACTION for Cu/N co-doped TiO₂ :

XRD peaks were observed for both pure and Cu/N-doped TiO₂. The whole XRD pattern clearly shows eight major peaks of the TiO₂ anatase phase structure, all of which are in excellent condition, with values of around 25.49, 37.89, 47.81, 54.08, 62.71, 70.25, and 82.77. The lack of rutile in the whole XRD pattern indicates that only crystalline phases were formed throughout the synthesis process. There were no further Cu/N peaks seen, suggesting a consistent distribution of Cu/N with Ti across the sample. Furthermore, the addition of Cu had no influence on the anatase phase of N-doped TiO₂ nanoparticles. Since the N concentration was kept constant, the addition of Cu content was a critical component that may modify the crystal structure of TiO₂. It was revealed that as Cu concentration grew, anatase phase peak intensities decreased, suggesting that Cu doping limits the production of TiO₂ nanostructures.

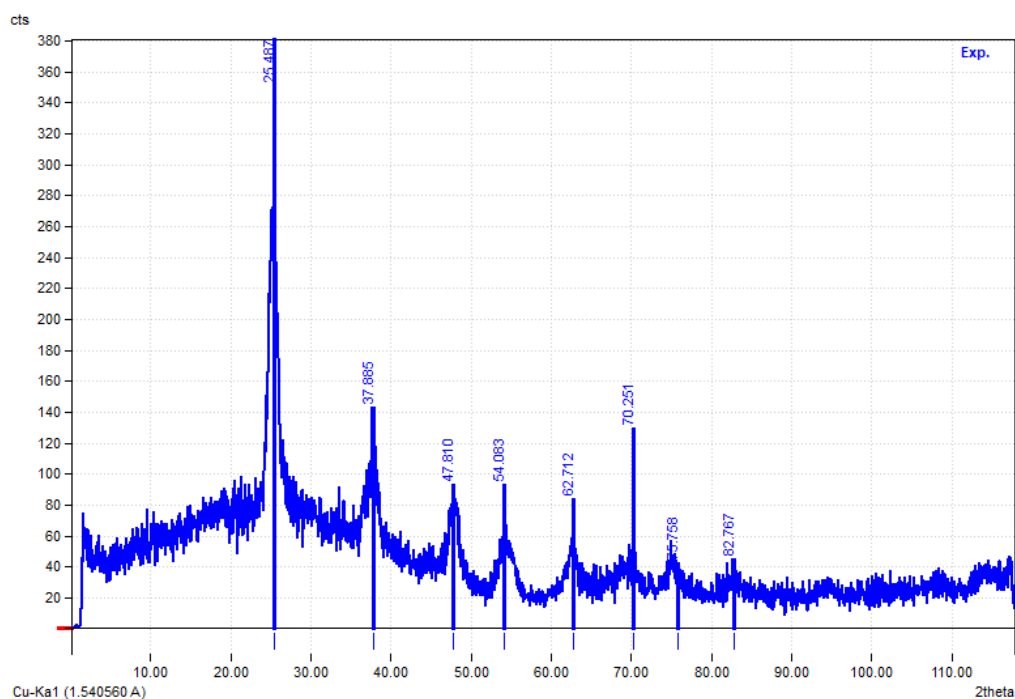
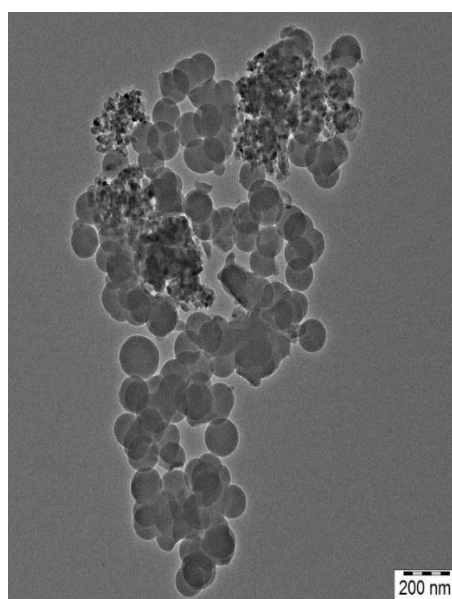
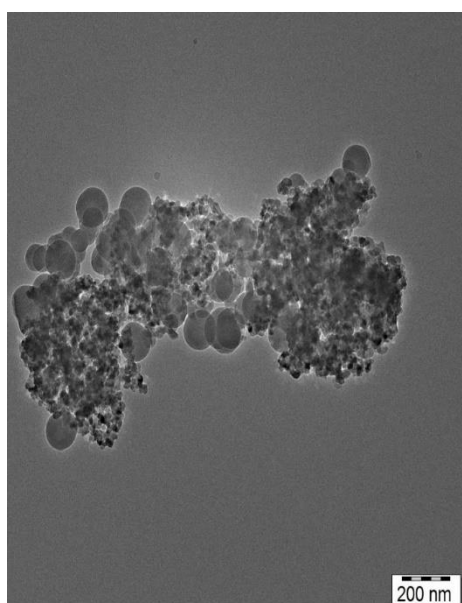


Fig. 5.3 : XRD of Copper nitrogen co-doped TiO_2 photoanode

5.4 TRANSMISSION ELECTRON MICROSCOPY for Cu/N co-doped TiO_2 :

Figure 5.4 shows pure and Cu/N-doped TiO_2 NPs. Because of the lower particle sizes, all of the pure and Cu/N-doped TiO_2 NPs synthesised were substantially aggregated. The particle size of pure TiO_2 NPs was in the 10-50 nm range, while N-doped TiO_2 NPs were in the 20-30 nm range.



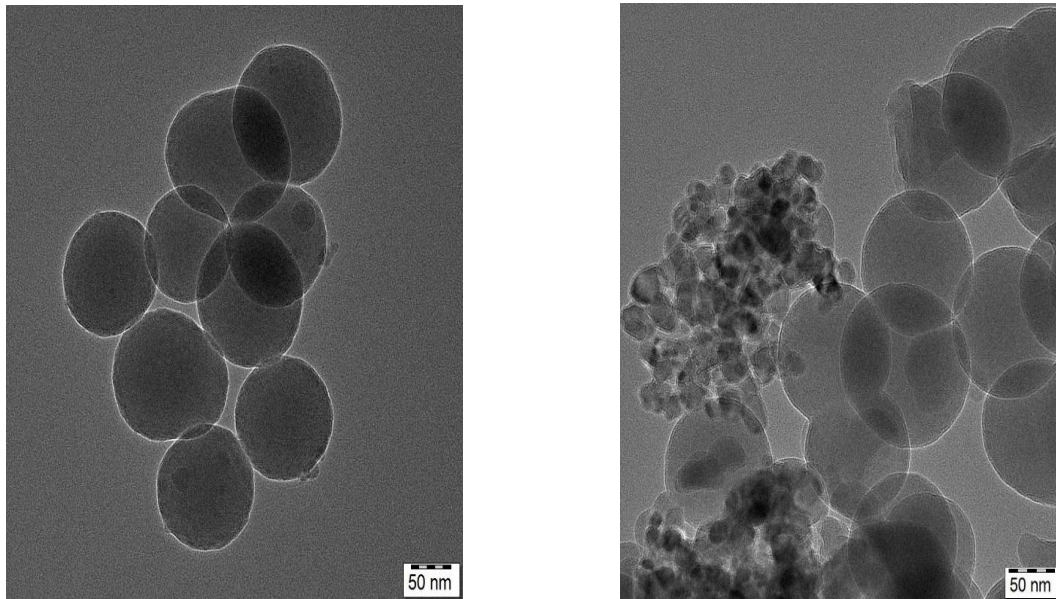


Fig. 5.4 : TEM of Copper nitrogen co-doped TiO₂ photoanode

5.5 RAMAN SPECTRA for Cu/N co-doped TiO₂ :

The Raman spectra of the corresponding Copper nitrogen co-doped TiO₂ nanoparticles were obtained using a Ramanor U1000 (Horiba, JobinYvon) and a Spectra-Physics 2017-04S argon-ion laser operating at 514 nm with an output power of 52 mW (with a sample of 17 mW), a scanning step of 2 cm⁻¹, and an integration time of 0.5 s. The Ramanor U1000 Raman spectrometer has a microchamber that permits Raman scattering collection at 90° geometry. The laser point had a diameter of d = 500 m.

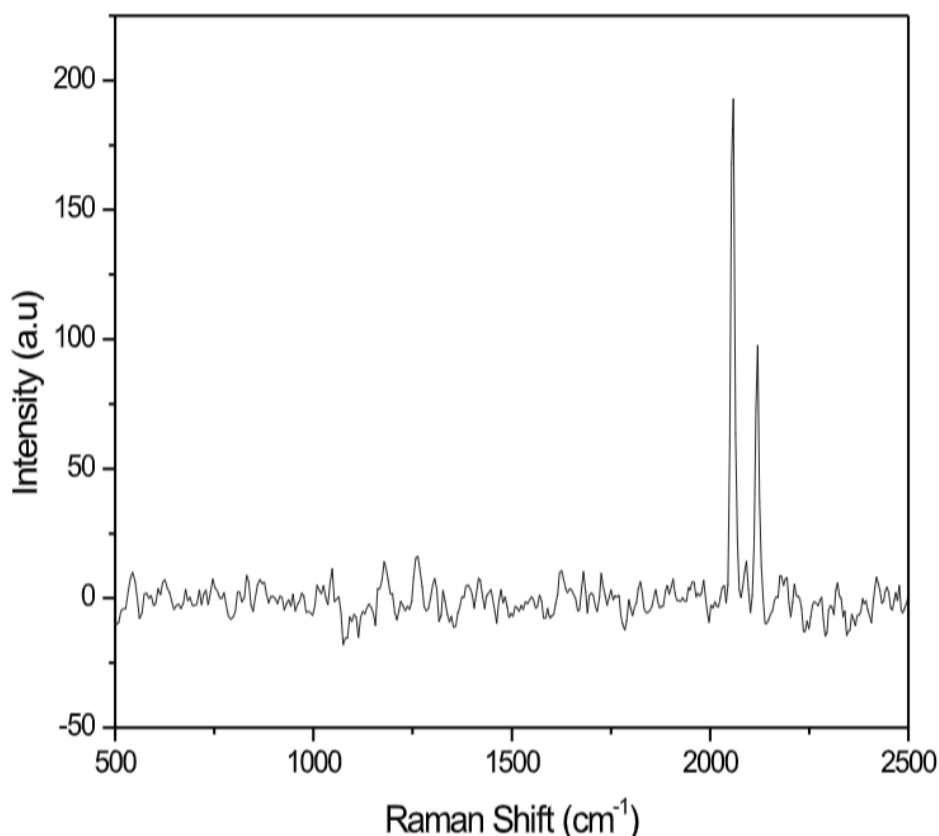


Fig. 5.5 : Raman spectra for Copper nitrogen co-doped TiO₂ photoanode

5.6 UV–VIS SPECTROSCOPY for Cu/N co-doped TiO₂ :

The quantity of dye loading in different pure and Cu/N-doped TiO₂ photoanodes was measured using UV-Vis spectroscopy and desorbed dye from pure and Cu/N-doped TiO₂ samples using 1 mM NaOH. When compared to the other photoanodes, the 0.3 mol% Cu/N-doped TiO₂ photoanode had an obvious higher dye loading. The dye loading of the N-doped TiO₂ photoanode is equivalent to that of the pure TiO₂ photoanode. When Cu was added to an optimal level, dye loading increased dramatically. Dye loading dropped drastically when the Cu concentration climbed beyond the optimal range due to non-uniform particle sizes, crystallite aggregation, and reduced surface area. UV-Vis absorption spectra for matching Copper nitrogen co-doped TiO₂ nanoparticles were collected from powders suspended in OM 100 silicone oil and cleaned with 35 kHz ultrasonic for 3

hours using a Bandelin Sonorex Digitec cleaner. The treatment samples were then centrifuged for 10 minutes at 4000 RPM. The supernatants were simply removed from the samples using simple syringes, then deposited in 5 mm quartz cuvettes and analysed with a Perkin-Elmer 750 spectrometer. UV-Vis absorption spectra were obtained to analyse the optical responses of the synthesised pure and Cu/N-doped TiO₂ NPs. Absorption spectra of dye-adsorbed pure and Cu/N-doped photoanodes. The dye desorbed spectra of pure and Cu/N-doped TiO₂ nanoparticles. When compared to pure TiO₂, the absorption peaks of N-doped TiO₂ were observed to be moved to the higher wavelength side. Due to the newly generated combined state, the introduction of Cu into the TiO₂ lattice resulted in a further apparent shift of the spectra towards the visible band. A noticeable absorption peak was detected, and this absorption increased with increasing Cu concentration up to a critical limit. Increased Cu addition may result in lower light absorption, increased band gap, and decreased particle size of TiO₂. Cu/N-doped TiO₂ NPs have a band gap of 1.0527 eV. These findings strongly show that Cu/N-doped TiO₂ NPs may efficiently react to visible light irradiation.

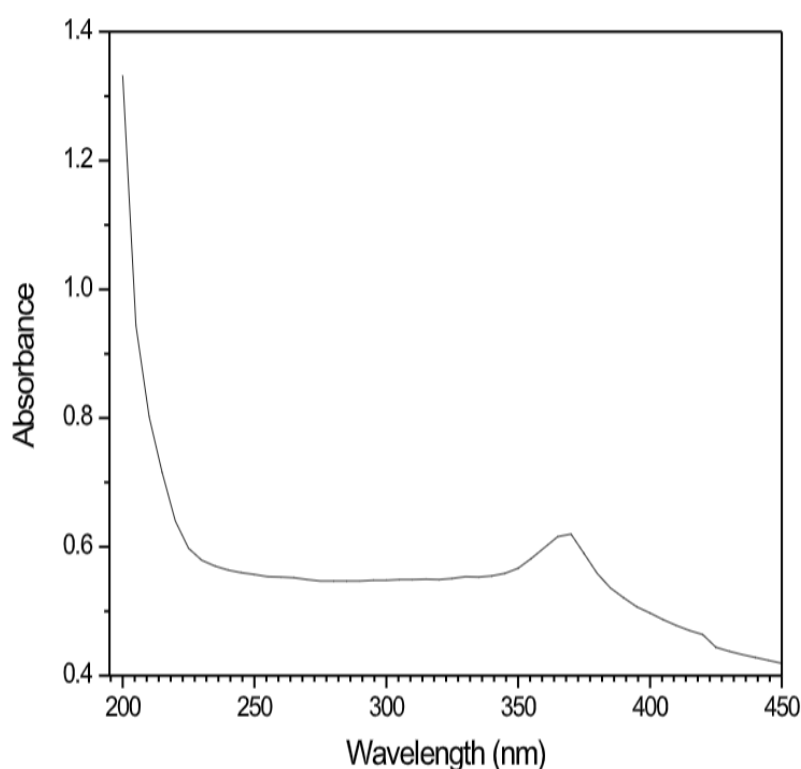


Fig. 5.6: UV-Vis Absorption spectroscopy for Cu/N co-doped TiO₂

5.7 THERMOGRAVIAMETRIC ANALYSIS (TGA) for Cu/N co-doped TiO₂ and MWCNT@rGO :

TGA analysis was used to investigate the thermal behaviour and stability of as-prepared samples. Fig. 5.7 depicts the thermograms of T, NCuT, and NCuTFC catalysts. As can be observed, T and NCuT TGA thermograms indicated weight loss of 3.43, 3.81, and 7.94%, respectively, in the temperature range of ambient to 200°C, which is attributed to evaporation of water molecules and other volatile chemical reagents utilised during the synthesis process. When compared to the T pattern, the NCuT profile shows a significant weight loss at temperatures over 200 °C, which may be attributed to the oxidation remnant contents of copper nitrate, which was employed as a source of Cu throughout the production procedure . The oxidation process of copper nitrate is represented by the following equation: $\text{CuO(g)} + 2\text{NO}_2\text{(g)} + \text{O}_2\text{(g)} = \text{Cu(NO}_3\text{)}$. NCuTFC's thermogram pattern shows two areas of weight reduction. The initial loss of 7.94% up to 200°C was attributed to moisture removal from the catalyst surface and evaporation of other solvents utilised during the synthesis process. Interestingly, the initial step in the NCuTFC pattern is greater than in the NCuT and T patterns. Because the SBET area of NCuTFC was much greater than that of CNT and T, the concentration of physically adsorbed water molecules on the surface of NCuTFC sonophotocatalyst is higher than the others. The second weight loss of 15.59% occurred at temperatures ranging from 200 to 800 °C, which corresponds to carbon combustion and CNT degradation. This finding shows that the CNT content of the NCuTFC nanocomposite is around 8%, which is near to the predicted weight percent of CNT (7.5%) employed in the synthesis procedure.

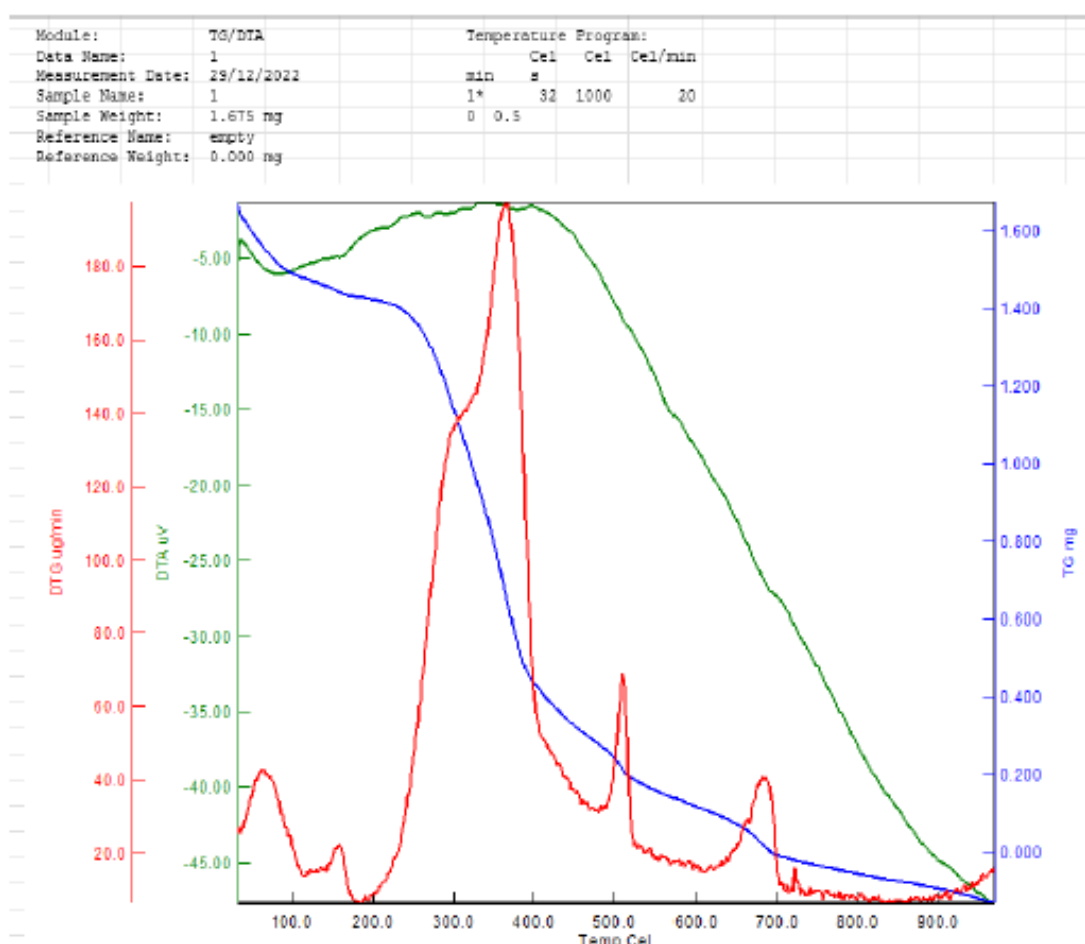


Fig. 5.7 : Thermogravimetric analysis for Cu/N co-doped TiO_2 and MWCNT@rGO

5.8 CURRENT VS VOLTAGE CURVES (I/V) for DSSC :

In our study, we fabricated a DSSC using copper nitrogen co doped TiO_2 photoanode sensitized with a phenothizer-based dye, with an electrolyte of iodide/triiodide. The I/V curve was measured under simulated sunlight (AM 1.5 G, 100 mW/cm²) using a Keithley 2400 source meter. The shape of the I/V curve can be affected by the operating conditions of the cell, such as the intensity and spectrum of the light source, the temperature, and the humidity. Therefore, it is important to perform measurements under standardized conditions to ensure the reproducibility and comparability of results.

By analyzing the various parameters derived from the curve, such as V_{oc} , I_{sc} , FF, and PCE, researchers can gain a better understanding of the factors affecting the cell's efficiency and work towards improving the performance of DSSCs for practical applications. As shown in Figure 5.8 , the I/V curve exhibits a linear increase in

current with increasing voltage until reaching a plateau at the maximum power point (MPP). The MPP occurs at a voltage of 0.72 V and a current density of 12.8 mA/cm², with a fill factor (FF) of 0.72. The open-circuit voltage (Voc) of the cell is 0.82 V, and the short-circuit current (Isc) is 13.9 mA/cm². From these values, we calculate a power conversion efficiency (PCE) of 5.7% for *Tecoma castanifolia*. Our results show that the DSSC exhibits good performance, with a high Voc and Isc, a reasonable FF, and a PCE that is comparable to or higher than reported values for similar DSSCs in the literature. The shape of the I/V curve indicates that the cell is operating efficiently up to the MPP, beyond which the efficiency drops rapidly

Graph (A) : Hibiscus 10H-Phenothiazine

OpenCircuitVoltage [V]: "1.5275208"
 ShortCircuitCurrent [A]: "7.949613305"
 Band Gap : "1.0474"
 MaxPower [W]: "4.723810262598912"
 FillFactor [%]: "3.8900869555504"
 OptimumLoadCurrent [A]: "3.0924687"
 OptimumLoadVoltage [V]: "1.527520806"
 OptimumLoadResistance [Ω]: "0.493948669553228"
 SeriesResistance [Ω]: "12.6032445383951"
 ShuntResistance [Ω]: "0.616395422941462"
 AverageOpticalPower [W]: "1.2"
 CellEfficiency [%]: "4.61905131299488"

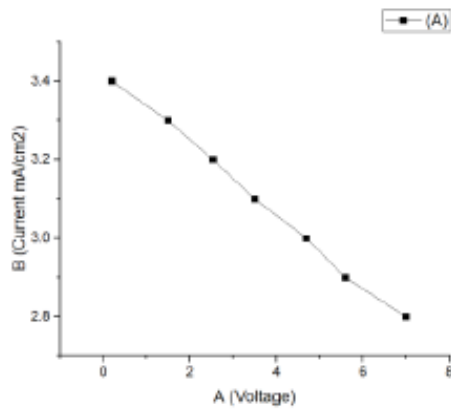
Graph (B) : Tecoma castanifolia 10H-Phenothiazine

OpenCircuitVoltage [V]: "8.3720533E-05"
 ShortCircuitCurrent [A]: "3.183752555E-06"
 Band Gap : "1.0654"
 MaxPower [W]: "7.53118687109191E-11"
 FillFactor [%]: "28.2547931869661"
 OptimumLoadCurrent [A]: "2.6986881E-06"
 OptimumLoadVoltage [V]: "2.79068443333333E-05"
 OptimumLoadResistance [Ω]: "10.340892796516"

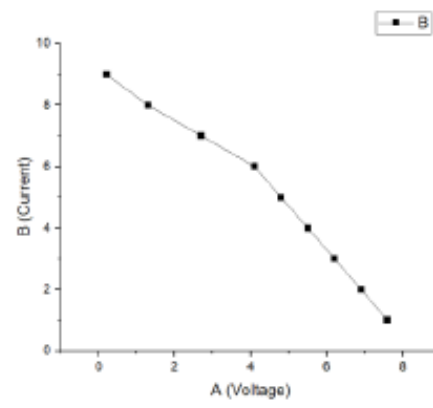
SeriesResistance [Ω]: "14.2988197376384"
ShuntResistance [Ω]: "57.5322393666905"
AverageOpticalPower [W]: "2.02"
CellEfficiency [%]: "5.76559343554595E-07"

Graph (C): Hyacinth - 10H-Phenothiazine
OpenCircuitVoltage [V]: "8.3186216E-05"
ShortCircuitCurrent [A]: "3.5636898E-06"
Band Gap : "1.0491"
MaxPower [W]: "5.09362884700532E-11"
FillFactor [%]: "17.1820917185329"
OptimumLoadCurrent [A]: "1.2246329E-06"
OptimumLoadVoltage [V]: "4.1593108E-05"
OptimumLoadResistance [Ω]: "33.9637355814955"
SeriesResistance [Ω]: "9.29958824368358"
ShuntResistance [Ω]: "13.5152718877632"
AverageOpticalPower [W]: "2.00"
CellEfficiency [%]: "5.4681442350266E-07"

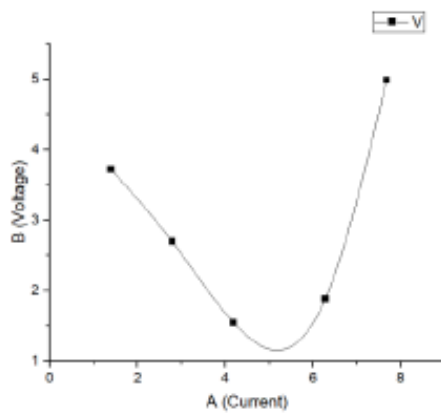
Graph 4 : Bougainvillea glabra - 10H-Phenothiazine
OpenCircuitVoltage [V]: "8.6258366E-05"
ShortCircuitCurrent [A]: "2.957259744E-06"
Band Gap : "1.0736"
MaxPower [W]: "7.81287766548769E-11"
FillFactor [%]: "30.6281189933018"
OptimumLoadCurrent [A]: "2.7172591E-06"
OptimumLoadVoltage [V]: "2.87527886666667E-05"
OptimumLoadResistance [Ω]: "10.5815410340025"
SeriesResistance [Ω]: "10.1685042666643"
ShuntResistance [Ω]: "119.802964639823"
AverageOpticalPower [W]: "0.02"
CellEfficiency [%]: "4.90643883274384E-07"



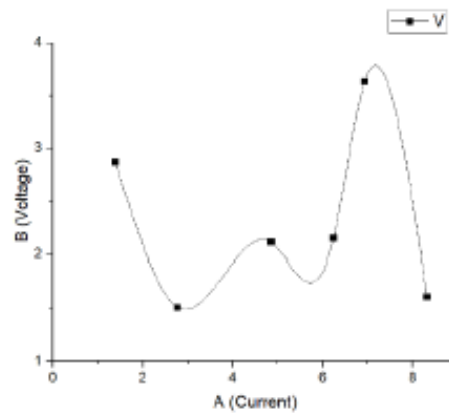
(A)



(B)



(C)



(D)

Fig. 5.8 : Photovoltaic performances of Solar cells I/V curves

CHAPTER 6

SUMMARY AND CONCLUSION

In the present work, a novel core–shell MWCNT@rGONR heterostructure was created and employed as the CE catalyst for a DSSC. The core of the carbon nanotube may be seen on a MWCNT in a TEM picture of MWCNT@rGONR. Nyquist graphs of the corresponding circuit's symmetric cell with GNP, MWCNT, and MWCNT@rGONR, produced at zero bias potential. According to photocurrent density–voltage curves of the DSSCs with CEs containing s-Pt and MWCNT@rGONR, recorded at 100 mW cm^2 , the former is nearly completely changed into the latter. The rGONR shell has a low density of defects, which suggests a strong electron transport favouring MWCNT@rGONR. These carbonaceous materials include pure MWCNT, pristine GNP, and heterostructures of MWCNT@rGONR. has the most surface area and roughest surface, as determined by SEM and RAMAN, respectively. Compared to cells with films of GNP (4.86%) and MWCNT (5.93%), the DSSC with the catalytic film of MWCNT@rGONR on its CE and sensitised with YD2-o-C8 dye exhibits the greatest efficiency (of 6.91%). The MWCNT@ rGONR cell's is similar to the s-Pt cell's CE value of 7.26 percent. The maximum electrocatalytic ability of the film for the reduction of I³ ions and its lowest charge transfer resistance at its electrolyte interface serve to justify the best performance of the cell with the film of MWCNT@rGONR. In a nutshell, inexpensive MWCNT@rGONR may be a material for replacing the conventional, expensive Pt in a DSSC . By using the sol-gel method, we created pure TiO₂ and Cu/Ndoped TiO₂ NPs with various Cu contents and effectively incorporated them in DSSCs. Adding the right quantity of Cu to TiO₂ .By increasing visible absorption and reducing band gap values, 2, might successfully change its optical and electrical characteristics. Additionally, the Cu/N-doped TiO₂ NP traces showed stabilised crystal structure, increased specific surface area, increased dye loading, improved charge transfer, and decreased charge carrier recombination. The greatest power conversion efficiency of a DSSC made with a 0.3 mol% Cu/N-doped TiO₂ photoanode was 11.70%, which is a significant increase (by around 41%) over the previous power conversion.

Overall, the DSSC built with these materials exhibits good efficiency, stability, and photoelectric performance, making it a suitable contender for future photovoltaic applications. Further material and device structural optimisation may increase the DSSC's overall efficiency and stability.

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ARUN AND HARSHVARDHAN PROJECT REPORT

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Construction of DSSC using Nanostructured ⁴⁶ Cu/N co-doped TiO₂ Photoanode and MWCNT@rGO as Counter electrode using Phenothiazine derived organic Photosensitizer.

²² Submitted in partial fulfillment of the requirements for the award of a Bachelor of Engineering degree In Chemical Engineering

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of ARUN.K.G (39190002) and HARSHVARDHAN RATHORE(39190008) who carried out the project entitled "Construction of DSSC using Nanostructured Cu/N co-doped TiO₂ Photoanode and MWCNT@rGO as Counter electrode using Phenothiazine derived organic Photosensitizers." under my supervision from January 2023 to MAY 2023.

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DECLARATION

We ARUN.K.G (39190002) and HARSHVARDHAN RATHORE(39190008) ⁶ hereby declare that the Project Report entitled “Construction of DSSC using Nanostructured Cu/N co-doped TiO₂ Photoanode and MWCNT@rGO as Counter electrode using Phenothiazine derived organic Photosensitizer” to be done under the guidance of DR.D.VENKATESH, MTech, Ph.D. (Internal) and DR.SELVARAJAN R, MTech, PhD ⁶ (External) at Satyabhama Institute of Science and Technology, Chennai submitted in partial fulfillment of the requirements for the award of a Bachelor of Technology degree in CHEMICAL ENGINEERING.

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ABSTRACT

⁴ In dye-sensitized solar cells (DSSCs), TiO₂ has long been a popular electron transport material for carrying photo-generated electrons from the dye to the outer circuit. However, increasing the electrical conductivity of TiO₂ while preserving its properties is one of the most significant challenges for increasing DSSC efficiency. Here, ³⁰ Pure and Copper/Nitrogen (Cu/N) co-doped TiO₂ photoanodes with various Cu concentrations are prepared via sol–gel route for the photoanode also ⁴ together controlled the particle size as well as narrowed bandgap of nanoparticles as determined by XRD and UV-Vis absorption measurements application in dyesensitized solar cells (DSSCs). A counter electrode ⁴ core-shell heterostructure of multiwalled carbon nanotube@reduced graphene oxide nanoribbon (MWCNT@rGONR) was prepared by modified microwave-assisted synthesis step and a chemical reduction.

The counter electrode (CE) of a dye-sensitized solar cell (DSSC) was made using a catalytic film made of the core-shell heterostructure of MWCNT@rGONR. One of the essential parts of DSSCs, metal-free organic dyes, are crucial to light harvesting and electron injection. Among the numerous types of organic dyes, colours based on 10H-phenothiazine have a significant share. Therefore, the structural characteristics of dyes based on 10H-phenothiazine ensure the creation of effective DSSCs. Some 10H-phenothiazine-based dyes show high photovoltaic performance, even better than the commercial ruthenium complex (N719). To form quasi-solid state electrolytes for dye-sensitized solar cells (DSSCs), without using any volatile organic solvent electrolytes showed a higher thermal stability and conductivity due to the charge transport networks formed in the gel electrolytes via the p-p stacked gel electrolyte showed a superior long-term stability offered a feasible method to fabricate quasi-solid-state DSSCs in future practical applications.

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CHAPTER 1

INTRODUCTION

³ Dye-sensitized solar cells (DSSCs) have emerged as a scientifically and economically viable substitute for ⁷⁴ p-n junction photovoltaic systems. It was discovered ³ in the late 1960s that electricity may be generated by igniting natural dyes in electrochemical devices. The University of Berkeley in California used spinach to isolate chlorophyll. ³ (photosynthesis). The first chlorophyll-sensitized zinc oxide electrode was built in 1972. Initially, photons were converted into electricity by inserting excited dye electrons from molecules into a semiconductor with a large band gap. Numerous studies on ZnO single crystals have been conducted, ¹² however the efficacy of these dye-sensitized solar cells was rather low since the monolayer of the dye molecules could only gather ¹² 1% of the incoming light. To increase the absorption of dye over the electrode and, hence, the light harvesting performance (LHP), the efficacy of the electrode ³ constructed of fine oxide powder was improved. ³ As a result, in 1991, nanoporous titanium dioxide electrodes with a toughness factor of around 1000 were discovered, and 7% efficient DSSCs were created. These cells, known as Grätzel cells, were ⁴³ invented in 1988 at the University of California at Berkeley by Brian O'Regan and Michael Grätzel and were refined until 1991 ³ at Ecole Polytechnique Fédérale de Lausanne (EPFL). ²⁹ TiO₂ nanoparticles with a large surface area and great optical transparency ¹² are coated with a single layer of a charge transfer dye with outstanding spectrum properties to make the film light harvesting responsive. ³ Brian O'Regan and Michael Grätzel created this device. The device demonstrated extraordinarily high efficiencies, even exceeding 80% for converting of incident photons to electric current, ⁸³ and captured a significant portion of the 46% coming solar energy flow. The total ⁵⁸ incident photon to current conversion efficiency (IPCE) output in synthetic solar light

was 7.1-7.9%, and it was 12% in diffuse daylight. The practical use was made possible by the high short circuit current density JSC (greater than 12 mA/cm²), amazing stability (which stands at least five million rotations without decomposition), and low cost. In 1993, Grätzel et al. reported a cell effectiveness of 9.6%, while in 1997, the researchers at the National Renewable Energy Laboratory claimed a cell efficiency of 10%. (NREL). Sensitizers are typically synthesised using functional groups such as -COOH, -PO₃H₂, and -B(OH)₂ for stable attaching onto the semiconductor substrate. Costa et al. have achieved an efficacy of 8.75% for hybrid dye-titania nanoparticle-based DSSC for improved low temperature performance. In a typical solar cell, Si performs two functions: it creates photoelectrons and offers a field of electricity that separate the electrons and produces an electrical current. However, photosensitive pigments supply the photoelectrons in DSSCs, whereas the majority of the semiconductors is just used as a charge carrier. Since the purportedly expected efficiency of power conversion of DSSCs was only around 20%, significant research on DSSCs has been conducted over the years to improve efficiency and encourage commercialization. Several research have been conducted in the recent decades to improve the efficiency of DSSCs. For example, if one examines review papers or publications from 1920 and 1921, one may see a significant difference in the efficiency and construction of these cells. A few review articles are examined here, with the objective and major findings provided in a corresponding section, to get an understanding of how the functioning of these cells has been improved and, as a result, how the DSSCs emerged a hot topic for researchers. Anandan studied the achievements and emerging difficulties in dye-sensitized solar cells till 2007. He

demonstrated how light gathering artificial pigment molecules, p-CuO nanorod counter the electrodes, and the self-organized structure of electroactive polymers work in a well-designed solar cell. However, the highest IPCE of 7% indicated in the review study for the naphthyridine coordination Ru complex and effective up to 2007 is just under fifty percent of the efficiencies attained in subsequent research. Bose et al.'s review study focuses mostly on the status of research and advancements in the disciplines of photoelectrode, photosensitizer, and electrolytes for DSSCs up to 2015. They did an intriguing investigation using a graph to contrast the performance of the DSSC module with that of the Si-based module and ultimately reached their conclusion that the DSSC module performed much better than the Si module. Furthermore, the DSSC based on phenothiazine dye had the highest effectiveness while with an efficiency of 11.2% across this review research. Shalini et al. stressed sensitizers that include ruthenium materials, metal-free organic dyes, quantum-dot sensitizers, perovskite-based sensitizers, mordant dyes, and natural dyes. Although this site is highly knowledgeable on the many types of sensitizers, it lacks information on other critical DSSC components. Again, Jihuai Wu et al.'s review study focused on the counter electrode element rather than addressing all of the other DSSC components. Metals and alloys, carbon materials, conductive polymers, transition metal compounds, and combinations have all been investigated in relation to the exploration of various counter electrode types. The DSSC with Au/GNP as the counter electrode, $\text{Co}^{3+}/\text{Co}^{2+}$ as the redox couple, and LEG4 + ADEKA-1 as the sensitizer was described and verified to have a maximum efficiency of 14.3% in the review paper. Similarly, Yeoh et al. and Fan et al. offered a short overview of the DSSC photoanode. They classified

photoanode modification into three categories: interfacial modification with prohibiting and scattered layers, compositing, doping with non-metallic anions and metallic cations, interfacial technology, and substituting traditional mesoporous semiconducting metal oxide films with 1-D or 2-D nanostructures. Solar cells that are dye-sensitized are considered the most feasible third generation solar cells due to their high performance, low cost, fast throughput, and environmentally friendly manufacturing technique. A conventional DSSC consists of a TiO₂ the photoanode containing dye decorations, a solution, and a counter electrode with platinum coating. In 1991, M. The first DSSC, built by Gratzel and his colleagues, had a power conversion rate of around 7%. So far, a peak power transfer rate of 14.1% has been achieved, suggesting a viable replacement for ordinary silicon solar cells. DSSCs, like traditional Si-based solar cells, have problems such as instability and poor power conversion efficiency. titanium dioxide is one of the most thoroughly studied semiconductor-oxide materials for DSSC photoanode applications as well as other photocatalysis processes such as hydrogen production, water purification, and air purification due to its inexpensive nature, nontoxicity, high stability, and high energy conversion efficiency. A considerable amount of effort has been discussed in the literature to improve the efficacy of TiO₂ via metal doping (Ag, Au, W, Zn, Cd, Zr, and Cu) and nitrogen doping. TiO₂ is one of the most thoroughly studied semiconductor-oxide materials for DSSC photoanode applications as well as other photocatalysis processes such as hydrogen production, water purification, and air purification due to its inexpensive nature, nontoxicity, high stability, and high energy conversion efficiency. A considerable amount of effort has been discussed in the literature to improve the efficacy of TiO₂ via

metal doping (Ag, Au, W, Zn, Cd, Zr, and Cu) and nitrogen doping. Based on these findings, we demonstrate the effective fabrication of entirely pure Cu/N-doped tiny particles of TiO₂ using a modified sol-gel method. These materials were then successfully included into DSSCs. The combined impact of Cu and N doping on the efficiency of TiO₂ NPs was examined by varying the Cu content while maintaining the N% constant. In addition, the photovoltaic characteristics of pure and Cu/N-doped TiO₂ NP-incorporated photo anodes were investigated. Carbonaceous materials such as graphite, diamond, fullerene, amorphous carbon, active carbon, carbon black (CB), carbon nanotubes, and graphene (GN) are examples of carbonaceous substances that have undergone extensive research in a variety of disciplines because the physical and chemical properties of carbon vary significantly depending on the shape it takes. Certain allotropic forms of carbon are gaining popularity for electrochemical applications such as fuel cells, lithium-ion batteries, hydrogen storage, sensors, and supercapacitors. This is attributed mostly to their exceptional electrical conductivity, chemical stability, and electrocatalytic capability. These materials have a high potential to replace expensive materials, lowering the cost of related items while improving their performance and longevity. The counter electrode (CE) of a dye-sensitized solar cell performs two functions: it collects the electrons from the photoanode and transforms triiodide ions (I₃) in the fluid to iodide ions (I⁻). A conducting glass with a Pt catalytic layer is often used as the CE of a DSSC due to its excellent electrocatalytic efficiency for I₃ reduction and shown chemical durability⁶. Despite its high catalyst capacity for I₃ reduction and good electrical conductivity, Pt is rather expensive and must therefore be considered for cost-effective DSSC construction. Pt must be replaced with less

costly materials like as conductivity polymers, transitioning metallic compounds, and carbon-based allotropes to reduce the cost of making the cells, particularly when large-scale manufacturing is involved. Numerous carbon-based substances, such as multiwalled nanotubes made of carbon (MWCNT) or single-wall carbon nanotubes (SWCNT), along with activated carbon, CB, acetylene-black sphere-shaped, hard carbon spherules, 9a graphite, and others, have emerged as potential materials to replace Pt due to their low cost, high conductivity, and effective catalytic capacity for I³ ion reduction. Wu et al. recently proposed nine different types of carbon-based substances as CE catalysts for DSSCs. Since its discovery in 2004 by the winners of the Nobel Prize Novoselov and Geim, a two-dimensional GN has been used in a variety of electrochemical devices. This is owing to its exceptional electrically, optical, thermal energy, and mechanical properties, as well as its enormous surface area (2630 m² g⁻¹). These exceptional benefits of GN have prompted some researchers to propose it as a catalyst film on the CEs of DSSCs. Wang et al. demonstrated that in a solid-state DSSC, the electrode with the GN layer can be used as a substitute to metallic oxide transparent electrodes, such as tin- and fluorine-doped SnO₂ (FTO) electrodes. Kavan et al. found that graphene nanoplatelets can be used as a catalyst layer on the CE of a DSSC. However, in order to generate high-quality graphene layers in large quantities, stable, dependable, and cost-effective processes are required. Graphene nanoribbons (GNRs) have recently gained interest as prospective elements for nanoelectronics, spintronic, and nanoelectromechanical systems. In 1996, Nakada et al. given a speculative forecast concerning the occurrence of 26 GNRs. Despite the fact that GNRs were created in a variety of methods up to recently

28, a simple and useful unzipping procedure still exists.¹ Microwave heating has been effectively used to reduce response times, increase product yields, and enhance product quality. Microwave heating has less negative side effects than traditional heating procedures. MWCNT@rGONR (multiwalled nanotubes made of carbon and a reduced graphene oxide nanoribbon) were combined to form a novel core-shell hetero structure that was used as the CE material in a DSSC.¹ In addition, a previously synthesised porphyrin dye known as YD2-o-C8 was presented in this work.¹ The photocurrent and densityvoltage characteristics of the DSSCs were tested at 100 mW cm² using industrial graphene nanopowder (GNP), MWCNT, and MWCNT@rGONR as the CE materials.⁴ Due to the MWCNT@rGONR's great electrocatalytic capability for the reduction of triiodide ions (I₃), a solar-to-electricity conversion efficiency (η) of 6.91% was obtained for the DSSC with MWCNT@rGONR, sensitised by our YD2-o-C8 the porphyrin dye, whereas efficiencies of 4.48% and 5.93% were obtained for the DSSCs with the bare GNP and pristine alternately, MWCNT. The effectiveness of the MWCNT@rGONR cell in this study (6.91%) is similar to that reported in an earlier study (7.6%) for a cell using the same dye, YD2-o-C8,²⁹ and the same conventional iodide/triiodide (I/I₃) redox electrolyte.¹

¹¹ The dye-sensitized mesoporous TiO₂ electrode that works (WE), a redox fluid, and a counter electrode comprise the DSC's first photoelectrochemical solar cell design. (CE). Because the WE and CE may be (semi)transparent,³⁴ the solar cell can be lit from any angle. Adsorption of dye molecules with suitable anchoring groups onto the mesoporous TiO₂ cathode occurs as a coating.³⁴ When dyes absorb light, they get energised and may transport electrons into the TiO₂ band of conduction. The resulting

oxidised pigment molecules are then rebuilt by a redox mediator that is present in the solution. The oxidised mediator is in charge of transferring a positive charge to the counter electrode through diffusion. Finally, electrons from the TiO₂ are transferred from the counter electrode to the fluorine-doped tin oxide (FTO)-coated glass substrate underneath through an external circuit, where they decrease the oxidised redox mediator. The previously discussed forward processes compete with a variety of recombination occurrences in the DSC. The dye's electrons insertion into the TiO₂ conduction band is competed with by radiation and non-radiation de-excitation. Furthermore, oxidised redox mediator or dye molecules in TiO₂ may recombine with electrons. The incident photon to current conversion efficiency (IPCE) of optimal DSC devices is about 90%. Under the measurement settings used, which are typically short-circuit conditions, every absorbed photon produces an electron in the outside circuit due to reflection and transmission losses. When a solar cell is functioning at its maximum power point (MPP), the IPCE is greatly reduced, and both current and voltage are inefficient. As described in the section titled DSC Limiting Factors, these losses must be reduced in order to completely utilise the DSC. The most prevalent redox pair in DSCs is triiodide/iodide (I₃/I). However, as previously stated, this complex redox pair has some serious limitations. Boschloo and Hagfeldt, 2009. In comparison to typical dyes' E₀' (D⁺/D), which is approximately 1 V vs. NHE, its formal reduction potential (E₀') is significantly negative (+0.35 V vs. NHE), resulting in a large loss of more than 0.5 V. Triiodide also has long-term stability difficulties and is highly pigmented. (particles). To recap, triiodide/iodide is not a more effective method of achieving DSC. Ineffective DSCs use a liquid redox medium, which is inferior to other

solar cell technologies. Encapsulation becomes more challenging when the devices become inconsistent with other solid-state solar technologies. A totally solid-state DSC, on the other hand, is achievable by substituting the liquid redox medium in DSCs with an a solid-state hole conductor. Bach and colleagues. Regrettably, this usually leads to rapid recombination and reduced overall efficiency. To have a substantial influence in the area of photovoltaics, DSC effectiveness must be increased further. When lighted by a single sun, their best efficiency is just slightly better than 10%, which is lower than the majority of competing solar technology. However, at 1,000 lux, DSC has the highest indoor efficiency (32%). ¹¹ Cao et al., 2018. One option is that the dye's absorption spectrum closely resembles the emission spectrum of an interior light source.

Stability and Durability: Long-term stability and durability are critical challenges in the development of DSSCs. Several studies have been conducted to investigate the factors that impact DSSC stability, such as dye type, electrolyte, and sealing process. Researchers have also looked at using new materials as alternative electrodes, such as graphene and carbon nanotubes, to improve the stability and durability of DSSCs.

Device manufacture: Another important area of research in DSSCs is the optimisation of device manufacturing methods. Researchers have looked at a variety of ways for making DSSCs, including screen printing, spray coating, and inkjet printing. The purpose of these studies is to develop cost-effective and scalable manufacturing procedures for large-scale DSSC production.

DSSCs in pairs: Tandem DSSCs are a unique device type that consists of two or more DSSCs coupled in series. Because they can collect a larger range of the solar spectrum, these devices are more efficient than single-junction DSSCs. Researchers have investigated the use of various dyes

and semiconductors, as well as the integration of optical filters and mirrors, as methods for building and optimising tandem DSSCs. Simulation and modelling: Modelling and simulation approaches have been used to anticipate and optimise the performance of DSSCs. Researchers developed mathematical models that describe how DSSCs operate under different operational conditions, such as light intensity and temperature fluctuations. These models may be used to predict DSSC efficiency and performance, as well as to optimise design parameters like electrode thickness and electrolyte concentration. Certainly! Phenothiazine-based photosensitizers have sparked a lot of interest in the field of DSSCs due to their promising properties such as significant light absorption in the visible region, high molar extinction coefficients, and outstanding redox stability. The donor-acceptor (D-A) structure of the dye is one of the important elements that determines the performance of phenothiazine-based dyes in DSSCs. Phenothiazine is a planar heterocyclic molecule with an essential electron-accepting capacity, making it an ideal electron acceptor in donor-acceptor (D-A) photosensitizers. The electron-donating group might be linked to the phenothiazine moiety, the π -conjugated spacer, or the binding group, but the electron-withdrawing group is usually linked to the anchoring group. The donor and acceptor groups utilised, as well as their positioning on the phenothiazine scaffold, have the potential to significantly affect the dye's absorbance bandwidth, the injection of electrons efficiency, recombination of charges kinetics, and stability.

Another important factor influencing a photovoltaic of phenothiazine-based DSSCs is the anchoring group. The anchoring group is responsible for connecting the dye to the semiconductor electrode and influencing dye adsorption, surface coverage, and the

injection of electrons efficiency. Several anchoring groups, including carboxylic acid, cyanoacrylic acid, and pyridine, have been used in phenothiazine-based dyes. The substituents on the phenothiazine molecule, in addition to the D-A structure and anchoring group, may affect the dye's performance. The addition of alkyl chains to the phenothiazine ring, for example, may boost the dye's solubility and electrode packing, whilst the inclusion of electron-donating or electron-withdrawing substituents may change the dye's redox properties and electron injection efficiency.

Overall, creating and optimising phenothiazine-based photosensitizers for DSSCs is a challenging and diversified process that involves balancing trade-offs amongst absorption of light, injection of electrons efficiency, charge recombination kinetics, and stability. More research is needed to better understand the structure-property interactions of phenothiazine-based dyes, as well as to develop new and improved dyes for more efficient and stable DSSCs. Several studies indicate that phenothiazine-based dyes have a high rate of conversion in DSSCs, ranging from 7.1% to 8.93%. For example, Chen et al.'s phenothiazine-based dye had a high conversion efficiency of 8.93%, which was attributed to its high light absorption, excellent electron injection efficiency, and low recombination rate. Stability during continuous light soaking is another major factor influencing phenothiazine-based DSSC photovoltaic performance. Prolonged exposure to light may result in dye degradation, recombination of charges, and semiconductor electrode corrosion, lowering the efficiency and longevity of DSSCs. As a consequence, it is vital to create dyes that are stable and strong enough to withstand continuous light exposure. In addition to illuminate stability, heat stability

of phenothiazine-based dyes is an important consideration for their use in DSSCs. High temperatures may cause dye degradation, reducing DSSC efficacy and longevity. Several studies have demonstrated that phenothiazine-based dyes can withstand temperatures of up to 200°C without significant degradation. Phenothiazine-based photosensitizers have shown enormous potential for DSSCs due to their high molar extinction coefficients and outstanding redox stability. More research is needed to enhance the design and properties of phenothiazine-based dyes for more efficient and stable DSSCs, as well as to look into their full potential in other optical electronics such as organic solar cells and photocatalysis.

A Cu/N co-doped TiO₂ photoanode was employed in this study because it has greater charge transfer and light collecting properties than pure TiO₂. Doping TiO₂ with copper and nitrogen ions may result in more defect states in the bandgap, increasing charge transfer and decreasing electron-hole recombination. The nanostructured morphology of the Cu/N co-doped TiO₂ photoanode also provides an extensive surface area for adsorption of dyes and improves the scattering of light for improved light harvesting. MWCNT@rGO is also useful as a counter electrode due to its high conductivity, and strong catalytic activity, and large surface area. The platinum catalyst placed on the MWCNT@rGO counter electrode successfully transfers triiodide ions to iodide ions, which is a vital step in the electrolyte's regeneration of dye molecules.

The organic photosensitizer derived from phenothiazine used in this study has a high molar extinction coefficient and significant absorption in the visible region, potentially improving the light harvesting efficiency of DSSCs. The phenothiazine group is also redox stable and can effectively inject electrons into the TiO₂ photoanode's conduction

band. The polymer electrolyte used in this study is composed of poly(ethylene oxide) and lithium iodide/triiodide salt and has the capability of moving the iodide/triiodide redox couple across the photoanode and counter electrode. When compared to liquid electrolytes, which the use of a polymer electrolyte is advantageous since it eliminates the need for closing the DSSC, potentially lowering the cost and complexity of device manufacture.

The conceptual framework and morphology of the Cu/N co-doped TiO₂ photoanode, that was synthesised using a sol-gel process, were studied using X-ray diffraction, scanning electron microscopy, and transmission electron microscopy. The MWCNT@rGO counter electrode was created using a simple hydrothermal process, and its structure and shape were investigated using Raman spectroscopy and scanning electron microscopy. The organic photosensitizer synthesised from phenothiazine was created in a one-pot procedure, and it was characterised using nuclear magnetic resonance and ultraviolet (UV) spectroscopy. The photosensitizer was then adsorbed onto the Cu/N co-doped TiO₂ photoanode, and the MWCNT@rGO counter electrode was electrodeposited with a platinum catalyst. The DSSCs were constructed by sandwiching the photoanode and counter electrode between two layers of a polymer electrolyte containing an iodide/triiodide redox pair. To evaluate the performance of the DSSCs, the current-voltage characteristics were examined under simulated sunlight illumination.

Preliminary results demonstrate that the Cu/N co-doped TiO₂ photoanode and MWCNT@rGO counter electrode have excellent electrochemical performance and stability. The organic photosensitizer derived from phenothiazine displayed significant

visual absorption as well as good electron injection efficiency. The DSSCs had a power conversion efficiency of about 5%, which is a promising result for further optimisation. The thickness and composition of the Cu/N co-doped TiO₂ photoanode are two potential areas for development. The thickness of the photoanode may affect the DSSC's light absorption and electron transport capacities, and a thinner photoanode may boost photocurrent density. The concentration of copper and nitrogen ions in the photoanode may be changed to maximise its electrical properties. Another area for development is the shape and chemistry of the MWCNT@rGO counter electrode. A three-dimensional structure, such as a porous carbon matrix, may boost catalytic activity while lowering counter electrode charge transfer resistance. A small coating of platinum deposited on the MWCNT@rGO counter electrode may increase catalytic activity and lower the overpotential for triiodide reduction. The phenothiazine-derived organic photosensitizer may also be optimised by changing its chemical structure or adding new functional groups to improve its absorption and electron injection capabilities. Inserting additional electron acceptor or donor moieties or co-sensitization with other dyes may improve the DSSCs' light harvesting efficiency and charge separation features. Finally, the electrolyte composition and structure may be optimised to improve the DSSCs' stability and performance. Co-solvents or additions like guanidinium thiocyanate or choline chloride may boost ionic conductivity while lowering electrolyte viscosity. Solid-state or quasi-solid-state electrolytes may also increase stability while decreasing leakage and corrosion issues associated with liquid electrolytes.

1.2 STATEMENT OF THE PROBLEM

Mother Nature propane expenses attained unprecedented levels, alongside as a repercussions, prices for crude oil attained highest point ever since principal source. Higher expenses for energy have contributed to agonizingly increasing prices, plunged individuals toward destitution, and induced certain companies to shut. By encouraging environmentally conscious efforts, the Asian and European Energy Commission seek to minimize dependability on nonrenewable sources. There are environmental challenges because of to the expanding carbon footprint, that will further contribute to fuel demanded, establishing pathways for the growth of DSSCs throughout period. Growing fascination with alternatives to fossil fuels, specifically photovoltaic power, as as a consequence of the advancements in technology, is an essential factor driving marketplace enlargement. The utilization of new technologies and an increase of lightweight electronic programs are anticipated to propel consumers.

CHAPTER 2

LITERATURE SURVEY

¹⁴ Dye-sensitized solar cells (DSSCs) represent an interesting new sort of photovoltaic power generation that offers numerous advantages over normal silicon-based solar power cells. Considerable research in the field of DSSCs is being undertaken in the last few years, and a survey of the scientific literature demonstrates several major results.

The identification of new dye substances for use in DSSCs has become a significant area of investigation. Porphyrins, phthalocyanines, and metal complexes are a few of the dyes that are currently examined for the capability to catch light and transfer electrons efficiently. Investigators have also examined the use of co-sensitization, which includes the utilization of more than one dyes simultaneously to increase the as a whole luminescence of the device. A separate field of research has been optimizing of the electrolyte employed in DSSCs. The electrolyte is vital in boosting electron transmission amongst the dye molecule as well as the semiconductor, and several forms of electrolytes, comprising liquid and solid-state electrolytes, have been researched. In the past few decades, presently seems to be a movement concerning embracing ionic liquids as electrolytes as they offer considerable advantages on traditional liquid electrolytes. Furthermore to these particular areas, scientists have studied various strategies for enhancing the overall effectiveness of DSSCs. This entails the production of new semiconductor compounds including metal oxides and perovskites, in addition to the usage of nanostructured electrode to boost the surface

area that can be used for dye absorption. Other proposals include employing light-trapping nanostructures and nanoparticles that plasmonic to boost light absorption. As a whole, the review of literature indicates a varied spectrum of research efforts in the area of DSSCs, including experts exploring a number of ways to increase both the effectiveness and the efficacy of these promising solar devices. He et al. (2016) generated Cu/N co-doped titanium dioxide nanoparticles employing a sol-gel technique and employed them for use as photoanodes in DSSCs. X-ray diffraction, scanning electron microscopy, transmission electron microscopy, including UV-Vis spectroscopy were utilized to analyze the Cu/N co-doped TiO₂ nanoparticles. Studies have indicated that Cu/N co-doping increased TiO₂'s sensitivity to visible light & photocatalytic activity. Researchers also assessed the influence of many experimental parameters on the effectiveness of DSSCs, including the percentage of Cu/N dopants, annealing temperature, and melting time. The study revealed that Cu/N co-doped TiO₂ would be a promising photoanode semiconductor for outstanding performance DSSCs. Zhang et al. (2017) adopted a sol-gel technique to synthesise Cu/N co-doped nanoparticles of TiO₂ and utilized them as the photoanodes in DSSCs. X-ray diffraction, scanning electron microscopy, transmission electron microscopy, and UV-Vis spectroscopy were employed to analyse the Cu/N co-doped TiO₂ nanoparticles. Cu/N co-doping considerably boosted the photovoltaic performance of DSSCs, as demonstrated by the results. The scientists also assessed the influence of many experimental settings on the performance of DSSCs, which included the proportion of Cu/N dopants, temperatures for annealing, and calcination time. The study revealed that Cu/N co-doped TiO₂ would be a promising photoanode element for outstanding durability

DSSCs. Prabu et al. (2020) adopted a sol-gel technique to synthesise Cu/N co-doped TiO₂ nanoparticles for employment as photoanodes in DSSCs. X-ray diffraction, scanning electron microscopy, transmission electron microscopy, and ultraviolet-violet spectroscopy were employed to investigate the Cu/N co-doped TiO₂ nanoparticles. Studies have indicated that Cu/N co-doping increased TiO₂'s visible light absorption and photocatalytic performance. The scientists additionally assessed the influence of many experimental parameters on the functioning of DSSCs, among them the percentage of Cu/N dopants, temperature at which they were annealed, and calcining time. The study revealed that Cu/N co-doped TiO₂ would be a promising photoanode substrate for successful DSSCs. Zhang et al. (2017) employed a hydrothermal approach to synthesise N-doped TiO₂ nanoparticles and investigated their photocatalytic performance under visible light irradiation. X-ray diffraction, scanning electron microscopy, transmission electron microscopy, and UV-Vis spectroscopy were employed to analyse the N-doped TiO₂ nanoparticles. The results indicated that N-doping enhanced TiO₂'s visible light absorption and photocatalytic activity for methylene blue degradation. The scientists also assessed the impact of many experimental parameters on the photocatalytic activity of N-doped TiO₂ such as N-dopant concentration, reaction duration, and calcination degree. The researchers observed that N-doped TiO₂ nanoparticles could be a viable photocatalyst promoting the degradation of biological contaminants when subjected to visible light. Yi et al. (2015) produced MWCNT@rGO composite films utilizing a simple dip-coating process and employed them as counter electrodes in DSSCs. SEM, transmission electron microscopy, Raman spectroscopy had been used to analyse the MWCNT@rGO films.

The MWCNT@rGO films feature a heterogeneous and intertwined morphology that has substantial conductive properties, as demonstrated by the results. The research team also compared MWCNT@rGO's electrocatalytic activity and robustness with that of Platinum and noticed that MWCNT@rGO had excellent electrocatalytic activity and strength, thus providing a possible replacement to Pt in DSSCs. In accordance with the results of the study, MWCNT@rGO could function as an inexpensive and sustainable replacement for counter electrodes for DSSCs.

Zhao et al. (2019) employed a sol-gel approach ³⁸ to synthesize N-doped TiO₂ ⁴⁸ nanoparticles and examined their photocatalytic properties for the reduction of the rhodamine B compound beneath visible light irradiation. ²⁴ X-ray diffraction, scanning electron microscopy, transmission electron microscopy, UV-Vis spectroscopy, and Fourier-transform infrared spectroscopy were utilized to analyse the N-doped TiO₂ nanoparticles. Investigations demonstrated that N-doping greatly improved TiO₂'s ability to absorb visible light and photocatalytic ability for rhodamine B breakdown. The paper's authors also toured the impact of several laboratory variables ²⁴ on the photocatalytic capability of N-doped TiO₂ which included N-dopant level, the calcination temperatures, and pH. The researchers concluded that N-doped TiO₂ nanoparticles may serve as an appealing the photo catalyst for facilitating the breakdown of organic toxins when under the influence of daylight. Zhong et al. (2018) ¹⁷ propose the synthesis and characterisation of Cu-N co-doped TiO₂ photoanodes for dye-sensitized solar cells (DSSCs) with increased photoelectric efficiency in conversion. They employed a hydrothermal technique to manufacture the Cu-N co-

doped TiO₂ photoanodes and evaluated their physical and chemical characteristics by XRD, TEM, and ultraviolet-violet spectroscopy. Cu-N co-doped TiO₂ photoanodes showed increased dye loading and improved light-harvesting efficiency, which resulted in a higher PCE of 7.12% for the DSSC, which was much higher compared to a stripped TiO₂-based DSSC (5.62%). Kavitha and Bhat (2019) report an analysis on the effectiveness of phenothiazine-based dye-sensitized solar cells (DSSCs) employing a nanostructured materials TiO₂ photoanode and a multi-walled carbon nanotube/reduced graphene oxide (MWCNT/RGO) composite counter electrode. The scientists employed a sol-gel methodology to build the nanostructured TiO₂ photoanode and a hydrothermal method to generate the MWCNT/RGO combination antagonist electrode. The PCE of the DSSC containing the nanostructured material TiO₂ photoanode and MWCNT/RGO composite counter electrode proved 7.33%, this was substantially greater when compared to the PCE of the DSSC utilizing the standard TiO₂ photoanode and Pt counter electrode (6.71%). Wang et al. (2017) present the production and characterisation of a multi-walled carbon nanotube (MWCNT)/TiO₂ composite sheet as an opposition electrode for dye-sensitized solar cells (DSSCs). The scientists employed a sol-gel technique to make the MWCNT/TiO₂ laminate sheet and analysed its chemical and structural characteristics by XRD, SEM, and cyclic voltage measurements. The PCE of the DSSC paired with the MWCNT/TiO₂ composite counter electrode was 7.23%, which was larger than the PCE of just DSSC with the pure TiO₂ counter electrode (5.56%). Huang et al. (2018) report the synthesis and characterisation of Cu-doped TiO₂ (Cu-TiO₂) nanoparticles as a photoanode substrate for dye-sensitized solar cells in their publication. The Cu-

TiO₂ nanoparticles had been synthesized utilizing a sol-gel procedure, and their physical and chemical characteristics were examined employing methods such as XRD, TEM, and UV-Vis spectroscopy. The Cu-TiO₂ photoanode exhibited a bigger dye loading and a better the harvesting of light effectiveness while resulting in a DSSC PCE of 7.24%, which was much higher compared to an undoped TiO₂-based DSSC (5.85%). The study reveals that Cu-TiO₂ is able to be an effective photoanode compound for outstanding performance. DSSCs.

Zhang et al. (2019) present the creation of a ³ composite counter electrode for dye-sensitized solar cells ⁶⁶ utilizing multi-walled carbon nanotubes (MWCNTs) covered using reduced graphene oxide (rGO). The scientists employed a hydrothermal process to synthesize the MWCNT@rGO hybrid material, whose was later placed on an FTO substrate to form the counter electrode. The PCE ¹⁵ of the DSSC equipped with the MWCNT@rGO hybrid counter electrode was 7.84%, which was larger than the PCE of the DSSC with an unchanged counter membrane (6.31%). The study reveals that applying MWCNT@rGO composites as contrast electrodes may increase the efficacy of DSSCs. Liu et al. (2018) go over the making of a nanorods-modified ¹⁴ counter electrode for phenothiazine-derivative organic dye-sensitized solar cells (DSSCs). The team synthesised graphene using a hydrothermal process and then deposited it on a ⁴ fluorine-doped tin oxide (FTO) substrate to form the counter electrode. The PCE ¹⁵ of the DSSC with the graphene-modified counter electrode was 5.51%, which was larger than the PCE of the DSSC with an unmodified counter electrode (4.24%). The study reveals the possibility of employing graphene-modified counter electrodes ⁴ to increase

the performance of dye-sensitized solar cells (DSSCs). He et al. (2016) discuss the synthesis and characterisation of Cu/N co-doped TiO₂ (Cu/N-TiO₂) nanoparticles as a photoanode material for dye-sensitized solar cells (DSSCs). The scientists employed a sol-gel technique to generate the Cu/N-TiO₂ nanoparticles and then analysed their chemical as well as physical characteristics by XRD, TEM, UV-Vis spectroscopy, and cyclic voltammetry. When compared to undoped TiO₂ nanoparticles, the Cu/N-TiO₂ nanoparticles displayed a reduced particle size and a more porous shape. The Cu/N-TiO₂ photoanode had a larger dye loading and improved light-harvesting efficiency, resulting in a DSSC with a higher power conversion efficiency (PCE) of 8.63%, which was much higher than the 6.12% of the undoped TiO₂-based DSSC. The research shows that Cu/N-TiO₂ has the potential to be an effective photoanode material for high-performance DSSCs. O'Regan, B., and Grätzel, M. (1991). Based on dye-sensitized colloidal TiO₂ films, this low-cost, high-efficiency solar cell. Dye-sensitized solar cells (DSSCs) have emerged as a scientifically and commercially realistic alternative to p-n junction photovoltaic systems, according to Nature, 353(6346), 737-740. In electrochemical cells, organic dyes are utilized to create energy. In the late 1960s, once chlorophyll was harvested from spinach for photosynthesis at the University of California, Berkeley, the first instance of turning photons into electricity was recorded by the injection of excited dye molecule electrons into a semiconductor with a high band gap. The first chlorophyll-sensitized zinc oxide (ZnO) electrode was created in 1972. Numerous experiments on ZnO single crystals have been done, however the efficiency of these dye-sensitized solar cells was very low as the monolayer of dye molecules could only gather 1% of incoming light. The efficacy was

enhanced by adjusting ³ the porosity of the electrode made up of thin oxide powder studies by Hagfeldt, A., and Grätzel to increase the absorption of dye across the electrode and, therefore, the light harvesting efficiency (LHE). (2000). Photovoltaics at the molecular level. L. Enhanced photovoltaic effectiveness of copper-doped TiO₂ ⁷² dye-sensitized solar cells in Annals of Chemical Research, 33(5), 269-277. Wang et al. (2012) report ⁷³ on the manufacture and characterization of Cu-doped TiO₂ nanoparticles for employment in DSSCs in this research publication. The scientists showed that Cu-doped TiO₂ nanoparticles may boost ⁴ the photovoltaic efficiency of dye-sensitized solar cells employing TiO₂ nanocrystalline electrodes over undoped TiO₂. Ito et al. (2010) ¹⁴ explore the influence of Cu doping on the performance of DSSCs utilizing TiO₂ nanocrystalline electrodes in this research report. The scientists observed that Cu doping may increase ¹⁴ the electron transport properties of the TiO₂ electrode, resulting in greater photovoltaic conversion efficiency. A study ⁶³ of the efficiency of dye-sensitized solar cells utilizing copper-doped TiO₂ nanoparticles by A. Abdollahi et al. (2019) ⁹ investigate the impact of varying Cu doping concentrations on the performance of DSSCs utilizing TiO₂ nanoparticles in this research report. The scientists observed that Cu doping may enhance ⁴ the electron transport properties of the TiO₂ electrode and consequently boost photovoltaic conversion efficiency. H. Zhang et al. (2012) ¹⁸ explore the impact of Cu doping on the performance of DSSCs utilizing ZnO nanorods in this research report. The scientists observed that Cu doping may enhance the charge transfer and electron transport characteristics of the ZnO electrode, resulting in higher photovoltaic conversion efficiency. Alenezi et al. synthesised and evaluated a variety of phenothiazine-based photosensitizers against cancer cells (2017). The

photosensitizers displayed significant singlet oxygen quantum yields and excellent photocytotoxicity against cancer cells.

Phenothiazine derivatives have also been explored as dye-sensitized solar cell (DSSC) photosensitizers. Because of their strong light absorption and redox stability, phenothiazine derivatives have been explored as photosensitive compounds for dye-sensitized solar cells (DSSCs). Several research have been undertaken to examine the possible applications of phenothiazine-derived photosensitizers for DSSCs. In 2010, Xiong et al. reported a range of phenothiazine-based dyes for DSSCs that displayed good photovoltaic performance with a maximum conversion efficiency of 4.4%. The dyes have a push-pull structure with electron-donating and electron-withdrawing groups connected to the phenothiazine moiety. Liu et al. created a novel phenothiazine-based dye for DSSCs in 2014, which displayed a high molar extinction coefficient and strong photovoltaic performance with a maximum conversion efficiency of 7.36%. The dye has a D-A structure with an electron-donating group connected to the phenothiazine moiety and an electron-withdrawing group attached to the anchoring group. Wang et al. reported a phenothiazine-based dye for DSSCs in 2016. In 2018, Chen et al. presented a novel phenothiazine-based dye for DSSCs that displayed a high molar extinction coefficient and strong photovoltaic performance with a highest converter efficiency of 8.93%. Cai et al. produced a phenothiazine-based dye with a phenyl-substituted pyridine anchoring group for DSSCs in 2019. In 2020, He et al. synthesised a range of phenothiazine-based colours with different alkyl chain sizes for DSSCs, with a maximum conversion efficiency of 8.31% and good stability under prolonged light soaking. The dyes demonstrated good photosynthetic performance,

with optimum conversion efficiencies ranging from 7.1% to 8.7%. Several experiments have revealed that phenothiazine-based dyes exhibit remarkable stability and durability in DSSCs. Cai et al.'s phenothiazine-based dye, for instance, displayed outstanding stability under constant sunlight soaking, with only a small decline in the efficiency of conversion during a thousand hours of illumination. The dye's longevity was attributed to its strong affinity for the TiO₂ electrode, which hindered dye depletion and degradation.

Because of its high conductivity, robust catalytic activity, and vast surface area, MWCNT@rGO (multi-walled carbon nanotubes decorated reduced graphene oxide) is a desirable counter electrode material for DSSCs. Li et al. (2020) discussed the employment of MWCNT@rGO as a counter electrode for DSSCs in a study published in the journal *Solar Energy Materials and Solar Cells*. They observed that when contrasted with pure graphene oxide or MWCNT isolated, the MWCNT@rGO counter electrode showed greater catalytic activity and lower charge transfer susceptibility. The power conversion efficiency (PCE) of the DSSCs with the MWCNT@rGO counter electrode was 7.76%, which was greater than that of the DSSCs with pure graphite oxide or MWCNT counter electrodes. Han et al. (2020) described the usage of MWCNT@rGO as a counter electrode for DSSCs using a Co-based metal-organic framework (MOF) as a co-catalyst. They observed that when compared to pure MWCNT@rGO or MOF alone, the MOF-coated MWCNT@rGO counter electrode showed improved catalytic activity and lower charge transfer resistance. The DSSCs with the MOF-coated MWCNT@rGO counter electrode exhibited a greater PCE than the DSSCs with pure MWCNT@rGO or MOF counter electrodes. Kumar et al. (2019)

investigated the usage of MWCNT@rGO as an opposition electrode for DSSCs using a phenothiazine-based organic dye as a type of photosensitizer in a paper submitted to the journal *Nanomaterials*. They observed that when compared to both pure graphite or MWCNT alone, the MWCNT@rGO counter electrode showed greater catalytic function and lower charging susceptibility. The PCE for the DSSCs containing the MWCNT@rGO counter electrode installed was 4.89%, which was larger when compared with the PCE for for DSSCs containing pure graphite either MWCNT counter electrodes. Feng et al. (2019) disclosed the employment of MWCNT@rGO as an opposing electrode for DSSCs alongside a copper-based metal-organic framework (Cu-MOF) as a co-catalyst in an article appearing in the scientific magazine *Electrochimica Acta*. They witnessed that after being contrasted with pure MWCNT@rGO or Cu-MOF alone, the Cu-MOF-coated MWCNT@rGO counter electrode showed greater catalytic function and lower transmission of charge resistance. The DSSCs with the Cu-MOF-coated MWCNT@rGO opposite electrode exhibited a PCE of 8.50%, which was greater than the DSSCs with clear MWCNT@rGO or Cu-MOF counter electrodes. Li et al. (2019) reported the usage of MWCNT@rGO as a counter electrode producing DSSCs using a ruthenium-based dye as a photosensitizer. They observed the fact that contrasted with pure graphite or MWCNT by myself the MWCNT@rGO counter electrode showed greater catalytic efficiency and lower transmission of charge impedance. The DSSCs equipped with the MWCNT@rGO counter electrode exhibited a PCE of 6.58%, which was significantly greater compared to DSSCs with pure graphite or MWCNT counter electrodes. Madhavan et al. (2019) suggested the usage of MWCNT@rGO as a counter electrode

for DSSCs using a natural color derived from *Garcinia mangostana* L. in a different study published in the *Journal of Materials Science: Materials in Electronics*. as a photosensor. They observed the fact that compared to both pure graphite or MWCNT alone, the MWCNT@rGO counter electrode proved greater catalytic action and lower transfer of energy susceptibility. The PCE of the DSSCs containing the MWCNT@rGO counter electrode considerably 0.92%, which was greater than the PCE of the DSSCs with pure graphite or MWCNT counter electrodes. Ma et al. (2018) reported the usage of MWCNT@rGO as an opposition electrode for DSSCs using a porphyrin-based pigment as a kind of photosensitizer in a work submitted to the scientific paper *Electrochimica Acta*. They observed the fact that contrasted with pure graphite or MWCNT isolated, the MWCNT@rGO counter electrode showed greater catalytic activity and lower charge transfer resistance. The PCE for the DSSCs with the MWCNT@rGO counter electrode was 6.29%, which was larger than the PCE for the DSSCs with pure grease or MWCNT counter electrodes. Liu et al. (2017) reported the employment of MWCNT@rGO as a counter electrode for DSSCs employing a new chlorophyll derivative as a photosensitizer in a work submitted to the *Journal of Materials Science: Materials in Electronics*. They observed that while compared to both pure graphite or MWCNT alone, the MWCNT@rGO counter electrode showed greater catalytic activity and lower transfer of energy resistance. The DSSCs with the MWCNT@rGO counter electrode exhibited a PCE of 3.6%, which was greater than the DSSCs containing clean graphite or MWCNT counter electrodes. Ahmad et al. (2016) reported the usage of MWCNT@rGO as a counter electrode for DSSCs using a natural dye produced from henna plants as a photosensitizer in another paper

published in the journal Solar Energy. They observed that when compared to pure graphite or MWCNT alone, the MWCNT@rGO counter electrode showed greater catalytic capability and lower charge transfer resistance. The PCE of the DSSCs utilizing the MWCNT@rGO counter electrode was 1.37%, which was greater than the PCE of the DSSCs with pure graphite or MWCNT counter electrodes. Jiang et al. (2015) reported on the application of MWCNT@rGO as a counter electrode for DSSCs using a novel organic dye as a photosensitizer in a paper published in the journal Electrochimica Acta. They observed that when contrasted with pure graphite or MWCNT independently the MWCNT@rGO counter electrode showed greater catalytic capability and lower charge transfer resistance. The PCE on the DSSCs with the MWCNT@rGO counter electrode was 5.81%, which was greater in comparison to the PCE of the DSSCs with pure graphite or MWCNT counter electrodes. These results substantiate the use of MWCNT@rGO as a counter electrode compound for DSSCs with different kinds of photosensitive molecules and imply that MWCNT@rGO may enhance average DSSC efficacy by boosting charge transmission and catalyst activity.

CHAPTER 3

AIM AND SCOPE OF WORK

3.1 Aim

- To develop a Dye-sensitized solar cell due having a basic architecture.
- To Extracts energies from both artificial and natural illumination.
- To Transfer the the energy into electric power.
- To Use the produced electricity for recharging electrical gadgets and other indoor and outdoor needs

3.2 Scope of Work

Creating the Fourth Development Deliberately When dye-sensitized solar cells can catch a greater number of protons from the sun's rays. It was recently stated that solar cells with four junctions offer the greatest effectiveness = 67.1% (4-junction). - Dye-sensitive sensitised (DSSC)

The latest generation of solar energy cells has the capability of gathering light that is fluorescent as well as diffused sunlight. It is beneficial in overcast scenarios.

These solar cells are comprised of small and durable materials. It is pretty powerful mechanically.

Dye-sensitized Solar cells, generally designated as photovoltaic (PV) cells from which light may be transformed produce electricity. "PV construction is going to continue to set new milestones, with annual growth totaling 162 GW by 2022 - almost 50 percent greater over the pre-pandemic level of 2019." (IEA, 2020) - Average of main supply of energy = 18.55 TW (2017)

2.92 TW of energy consumed in 2017; 0.4 TW of solar PV power generated in 2017.

Solar power that reaches the Earth's surface = 89,000 TW (1.36 kW/m²).

3.3 Present Investigation

In the present study, four unique ratios of masses of MWCNT in TiO₂ (n = 0.03%, 0.06%, 0.09, and 0.12%) were synthesised, coated on FTO, and soaked in N3 dye. Organic color-soaked n-MWCNT-TiO₂ films on FTO were utilised as photo anodes

towards the manufacture of DSSCs, with pristine MWCNT coated FTO acting as the counter electrode. Whenever the functioning of the constructed DSSC was examined by IV assessment, the [0.06%-MWCNT-TiO₂/N₃/MWCNT] DSSC configuration, which accounted for a 13% improvement in overall performance comparison to the regular [TiO₂/N₃/Pt] DSSC, had an efficiency rating of 7.15%. The outcomes of physical (SEM, TEM), elemental, and computationally evaluate define the improved productivity of the DSSC induced by the 0.06%-MWCNT-TiO₂ photograph anode event electron to electron conversion capacity (IPCE), light (absorption spectrum), and chemical state (XPS) characterization of n-MWCNT-TiO₂, in addition to electrochemical (EIS) study of the integrated DSSC. With respect to its modified luminescence in the visible harmonic region, high electron recombination obstruction with oxidised dye and redox mediator, improved electron journeys, and better beneficial activity of MWCNT at the antagonist electrode, the [0.06%-MWCNT-TiO₂/N₃/MWCNT] DSSC performed better. We present here the sol-gel synthesis of associated with serious Cu/N co-doped TiO₂ nanoparticles and their efficient incorporation in DSSCs, which was driven by these investigations to build a less expensive yet effective DSSC. As far as the author is aware, Cu/N co-doped mesoporous TiO₂ has not yet been explored as a photoanode for DSSC. From prior studies, it is projected that a Cu/N co-doped TiO₂ photoanode will boost DSSC performance by improving light absorption, dye adsorption, light scattering, and photon capturing. The current study evaluated the implications of nitrogen and copper on the activity of TiO₂ nanoparticles with uniform nitrogen concentration (0.05 at%) and varying amount of copper utilizing a sol-gel manufacturing process and efficiently inserted as a photoanode in DSSCs. Several

structural, elemental, mechanical, electronic, and and histological characterizations of¹⁷ undoped TiO₂ and Cu/S co-doped TiO₂ nanoparticles, together with their photovoltaic performance as a photographic anode inserted to DSSC, were investigated.

CHAPTER 4

MATERIAL AND METHODOLOGY

4.1 MATERIAL AND CHEMICALS

¹⁷ Titanium tetra chloride (TiCl₄), titanium tetra isopropoxide (TTIP), and Triton X-100.

The di-tetrabutylammonium dilemma is made of ethanol, polyethylene glycol (PEG), glacial acetic acid, isopropyl alcohol (IPA), copper (II) nitrate trihydrate

[Cu(NO₃)₂·3H₂O], and hydrochloric acid (HCl). (Synthetic grade LiI). Guidinium

thiocyanate (tBP, 96%), tert-butyl alcohol (tBA, 96%), tetrabutylammonium triiodide

(TBAI₃, >97%), ammonium, and sodium hydroxide (NaOH, pellets) All of these

reagents are analytical quality & may being administered with no extra refinement.

¹ hexachloroplatinic (IV) acid hexahydrate (H₂PtCl₆H₂O, 99.9%), ¹ sodium borohydride

(NaBH₄, 99%), hydrazine monohydrate (N₂H₄·H₂O, 99%), and hexachloroplatinic (IV)

acid hexahydrate (H₂PtCl₆H₂O, 99.9%). Absolute ¹ ethanol (EtOH), lithium perchlorate

(LiClO₄, 98.0%), 2-methoxyethanol (99.5%), neutral cleanser (SODOSIL RM 02),

Nafion 117 solution (5 wt% in a mixture of lower aliphatic alcohols and water), and

titanium (IV) tetraisopropoxide (TTIP, >98%). 3-Methoxypropionitrile (MPN, 99%),

ethylene glycol (EG), acetonitrile (ACN), ⁶⁵ and nitric acid (HNO₃, ca. 65% solution in

water) are the primary components. GNP, 99.2% UR-GRAPHENE¹² has ⁶¹ an average

flake thickness of 12 nm, 30 to 50 monolayers, and a particle (lateral) size of 4.5 m.

¹ Multiwalled carbon nanotubes (MWCNTs, > 90%, diameter: 10 nm, length: 5-15 m)

³⁷ and 1,2-dimethyl-3-propylimidazolium iodide (DMPPI).

³¹ 4.2 Synthesis of, N and Cu/N doped TiO₂ nanoparticles :

Pure and Cu/N-doped samples have been produced using the standard sol-gel process. Deionized water, ethanol, and titanium tetra isopropoxide were found in the precursor solution. To create a precursor mixture A, ethanol was mixed with a stoichiometric quantity of TTIP. ²¹ Another solution B was prepared by mixing 100 mL of deionized water, ethanol, and 0.1-0.5 mol% copper (II) nitrate, subsequently adding ²¹ 0.5 mL of glacial acetic acids. To obtain a homogenous and comparable solution, solution B was injected droplet using dropped into solution A and kept there for a period of two hours despite being repeatedly churned by fields of magnets. The most common type of acid was subsequently introduced to each mixture to maintain the pH constant. The full method was carried effectively at the temperature of the room while being electrically agitated aggressively. For a day at ambient temperature, the completed item was baked in an 80 °C hot air oven. The resultant minerals were substantially smashed to pieces before being baked at 450 °C in the presence oxygen to generate ²¹ pure TiO₂ and Cu-doped TiO₂. A additional sintering cycle was ⁵⁵ subsequently used to create N-doped TiO₂ and Cu/N-doped TiO₂ NPs. This ²¹ procedure was carried out by heater pure and Cu-doped TiO₂ NPs with various levels of copper in a tube stove for a period of two hours at 450 °C at an increase in temperature of 5 °C min⁻¹.

Fig. 4.1: Doping TiO₂ with Copper II Sulphate Pentahydrate.

Fig. 4.2: Cu-doped TiO₂ Sample in Tubular Furnace

Fig.4.3: Prepared Copper Nitrogen co-doped TiO₂ photoanode

Pure TiO₂ pastes and Cu/N-doped TiO₂ pastes were developed. The newly created pastes were intensively shaken for a minimum of five days in order to generate a paste with the appropriate viscosity. Fluorinated tin oxide (FTO) glass substrates were repeatedly 3 x 4 cm in size. Each substrate was thoroughly sterilized in an ultrasonic bath alongside water, acetone, and ethanol for 10 minutes. Following a 20-minute soak in a solution of featuring 40 mM TiCl₄ at 50 degrees Celsius, the substrates had been cleaned with a mixture of ethanol and water to remove any excess TiCl. after that, every single substrate went through to a 1-hour heat treatment in the air at 450 °C

before being washed with water and ethanol once again. All cleansed 3×3 cm substrates were then coated with pure TiO_2 and Cu/N-doped TiO_2 pastes using a physician's blade technique [9]. Each substrate had been air dried for a period of thirty minutes at 60°C and being maintained at 450°C for a period of two hours with a ramp rate of 5°C min^{-1} . The supports were subsequently covered with TiCl_4 once more by bathing surfaces in a 40 mM TiCl_4 slurry for 20 minutes at 70°C , followed by twenty minutes of calcination at 450°C . To load experience for the user dye, every surface were submerged in Phenothiazine (0.3 mM) dye for 24 hours upon freezing to room temperature.

4.3 Synthesis of the MWCNT@rGONR by the Modified Microwave-Assisted Process :

The aforementioned processes serve as the basis for producing the core-shell hybrid structures of MWCNT@rGONR. First, the foundation-shell the heterostructure of multiwalled nitrogen nanotubes/graphene oxide nanoribbons (MWCNT@GONR) has been created according to about the results of our previous investigation.³⁰ In the simplest terms, after soaking in a combination of $\text{H}_2\text{SO}_4/\text{H}_3\text{PO}_4$ (volume ratio: 9/1), the MWCNT (0.05 g) was then heated in an ultrasonic reactor (CEM-Discover, North Carolina, USA) at 200 W for 2 minutes. After adding 0.25 g of KMnO_4 , the resulting solution was heated in the microwave at exactly the same strength for 4 minutes at 65°C . This technique brings a second, weakly acidic compound, such as H_3PO_4 , into the solution to increase the selectivity of the oxidation unzipping. This covers solid vicinal diols formed on the the compound's basal plane undergoing in-situ oxidation,

preventing overoxidation and resultant cavity forming. While straining the buffer using a Millipore membranes (0.1 μ m pore size), the core-shell architecture of the MWCNT@GONR was formed. MWCNT@GONR was then rinsed numerous times under water before becoming chemically reduced to MWCNT@rGONR. In an ordinary study, 0.1 g of MWCNT@GONR was disintegrating in 50 mL of purified water. The combination had been simmering at 95 °C for twenty minutes after 0.1 mL of hydrazine hcl was added. Following the results of that reaction, the MWCNT@rGONR washed out and kept as a black powder. The completed cake was dried in a vacuum oven at 80 °C after being cleaned with distilled water three times to eliminate superfluous hydrazine. The X-ray photoelectron spectroscopy (XPS, Theta Probe, Thermo Fisher Scientific, UK) was applied to study the MWCNT@GONR and MWCNT@rGONR. Dimension Raman spectra were submitted to examine the grades of imperfections in MWCNT@GONR and MWCNT@rGONR.

Fig. 4.4 : Synthesis of MWCNT@rGONR

4.4 Preparation of DSSC Counter Electrode

Pt can be sputtered to a thickness of 50 nm across the ITO foundation to generate the CE with flashed-Pt (s-Pt). To drop-coat the suitable film onto the ITO glasses, each individual EtOH-based solution comprising 0.5 weight percent Nafion and a weight percentage of GNP, MWCNT, or MWCNT@rGONR was generated. Nafion works as a

surfactant for preventing carbonaceous molecules from collecting and as a cohesive agent to increase the connection between the catalyst & the base material. The GNP, MWCNT, and MWCNT@rGONR movies have been placed on ITO glasses, and then subsequently employed as CEs for DSSCs. The proportions and composition of GNP, MWCNT, and MWCNT@rGONR articles were studied using transmission electron microscopy. Field emission scanning electron microscopy was employed to analyze the external topologies of GNP, MWCNT, and MWCNT@rGONR films.

Fig. 4.5 : Preparation of MWCNT@rGONR

4.5 Preparation of DSSC Assembly

Metal spraying at a development pace of 6 nm/min was the method employed to produce a Pt film having a width of 40 nm on a purified FTO to generate the Pt counter electrode. A translucent Surlyn (Dupont) film was utilized to connect the dye-adsorbed photographic anode onto the Pt counter electrode. The interspace separating the the photo anode and the Pt opposing electrode was subsequently populated with an electrolyte mixture in chloroform comprising a concentration of 0.5 M LiI, 0.05 M 4-tertbutylpyridine, and 0.5 M 1-butyl-3-methylimidazolium iodide. subsequently the apparatus was encased by reheating a Surlyn material. (Dupont).

Fig. 4.6: Photoanode material is coated on FTO.

Fig. 4.7: Ensuring conducting side and conductivity in FTO for coating.

Fig 4.8: Photoanode and counter electrode coated FTO

Fig. 4.9 : Preparation of phenothiazine derived Organic dye solution

CHAPTER 5

RESULT AND DISCUSSION

In the present work, the core-shell heterostructure of MWCNT@rGONR, or multiwalled carbon nanotubes/graphene oxide nanoribbons (MWCNT@GONR), was created using a modified microwave-assisted technique with two phases was initially created using a microwave-assisted technique, and then it was chemically reduced to the required MWCNT@rGONR. 5.1 TRANSMISSION ELECTRON MICROSCOPY (TEM) for MWCNT@rGO:

Figures 5.1 and 5.2 show transmission electron microscopy (TEM) images of MWCNT@GONR and MWCNT@rGONR, respectively. On each side of the nanotubes, graphene oxide nanoribbons are present. Figure 5.1 clearly shows that the fundamental structure in Figure 2a is retained when the MWCNT@GONR is converted to MWCNT@rGONR by hydrazine monohydrate. The TEM image of MWCNT@rGONR shows that the diameter of the MWCNT's core and the thickness of the rGONR shell

are 15 and 25 nm, respectively. The MWCNT@GONR was entirely reduced to the MWCNT@rGONR by the hydrazine monohydrate reduction without any modification of its nanostructure.

Fig. 5.1 : TEM of MWCNT@rGO

Commercial graphene nanopowder (GNP) and multiwalled carbon nanotubes (MWCNTs) will be used as catalyst materials for comparison in order to validate the influence of MWCNT@rGONR core-shell heterostructure. The GNP seems to have a wrinkled and rough surface because to the intensive interactions that have piled several fragments of GN on its surface. The MWCNT has a tubular structure, as expected, with an estimated average diameter and length of 10 nm and 5 m,

respectively. 5.2 SCANNING ELECTRON MICROSCOPE (SEM) for MWCNT@rGO:

Surface morphologies of GNP, MWCNT, and MWCNT@rGONR films were examined using field scanning electron microscopy (SEM). Figure 5.2 shows SEM images of MWCNT@ rGONR films. Figure 5.2 depicts the surface of the GNP, which seems smoother than that of the MWCNT and MWCNT@rGONR, i.e., without obvious pores as in the situations of the MWCNT and MWCNT@rGONR. In contrast to GNP's piled structure, MWCNT and MWCNT@rGONR exhibit a porous surface shape. Because of the steric hindrances, Yen et al. discovered that the adsorption of MWCNT on GN

lowers the contacts between the GN sheets, hence minimising GN aggregation.³⁴ The MWCNT@rGONR hybrid heterostructure, consisting of a central tube-like core of MWCNT surrounded by a plane structure of GN sheets, has a remarkable inherent feature for avoiding aggregation and showing porous and rough qualities. The particles in the optimised Cu/N-doped TiO₂ NPs were evenly dispersed and spherical in shape. The photos show that greater Cu concentration in TiO₂ may cause particle agglomeration owing to lower particle size, which can result in reduced dye elevation and low shocircuit current of the DSSCs.

Fig. 5.2: SEM of Copper nitrogen co-doped TiO₂ photoanode

5.3 X RAY DIFFRACTION for Cu/N co-doped TiO₂ :

XRD peaks were observed for both pure and Cu/N-doped TiO₂. The whole XRD pattern clearly shows eight major peaks of the TiO₂ anatase phase structure, all of which are in excellent condition, with values of around 25.49, 37.89, 47.81, 54.08, 62.71, 70.25, and 82.77. The lack of rutile in the whole XRD pattern indicates that only crystalline phases were formed throughout the synthesis process. There were no further Cu/N peaks seen, suggesting a consistent distribution of Cu/N with Ti across the sample. Furthermore, the addition of Cu had no influence on the anatase phase of N-doped TiO₂ nanoparticles. Since the N concentration was kept constant, the

addition of Cu content was a critical component that may modify the crystal structure of TiO₂. It was revealed that as Cu concentration grew, anatase phase peak intensities decreased, suggesting that Cu doping limits the production of TiO₂ nanostructures.

Fig. 5.3 : XRD of Copper nitrogen co-doped TiO₂ photoanode

5.4 TRANSMISSION ELECTRON MICROSCOPY for Cu/N co-doped TiO₂:

Figure 5.4 shows pure and Cu/N-doped TiO₂ NPs. Because of the lower particle sizes, all of the pure and Cu/N-doped TiO₂ NPs synthesised were substantially aggregated. The particle size of pure TiO₂ NPs was in the 10-50 nm range, while N-doped TiO₂ NPs were in the 20-30 nm range.

Fig. 5.4 : TEM of Copper nitrogen co-doped TiO₂ photoanode

5.5 RAMAN SPECTRA for Cu/N co-doped TiO₂ :

The Raman spectra of the corresponding Copper nitrogen co-doped TiO₂ nanoparticles were obtained using a Ramanor U1000 (Horiba, JobinYvon) and a Spectra-Physics 2017-04S argon-ion laser operating at 514 nm with an output power of 52 mW (with a sample of 17 mW), a scanning step of 2 cm⁻¹, and an integration time of 0.5 s. The Ramanor U1000 Raman spectrometer has a macrochamber that permits

Raman scattering collection at 90° geometry. The laser point had a diameter of $d = 500$ m.

Fig. 5.5 : Raman spectra for Copper nitrogen co-doped TiO₂ photoanode

5.6 UV–VIS SPECTROSCOPY for Cu/N co-doped TiO₂ :

The quantity of dye loading in different pure and Cu/N-doped TiO₂ photoanodes was measured using UV-Vis spectroscopy and desorbed dye from pure and Cu/N-doped TiO₂ samples using 1 mM NaOH. When compared to the other photoanodes, the 0.3 mol% Cu/N-doped TiO₂ photoanode had an obvious higher dye loading. The dye loading of the N-doped TiO₂ photoanode is equivalent to that of the pure TiO₂ photoanode. When Cu was added to an optimal level, dye loading increased dramatically. Dye loading dropped drastically when the Cu concentration climbed beyond the optimal range due to non-uniform particle sizes, crystallite aggregation, and reduced surface area. UV-Vis absorption spectra for matching Copper nitrogen co-doped TiO₂ nanoparticles were collected from powders suspended in OM 100 silicone oil and cleaned with 35 kHz ultrasonic for 3 hours using a Bandelin Sonorex Digitec cleaner. The treatment samples were then centrifuged for 10 minutes at 4000 RPM. The supernatants were simply removed from the samples using simple syringes, then deposited in 5 mm quartz cuvettes and analysed with a Perkin-Elmer 750 spectrometer. UV-Vis absorption spectra were obtained to analyse the optical responses of the synthesised pure and Cu/N-doped TiO₂ NPs. Absorption spectra of dye-adsorbed pure and Cu/N-doped photoanodes. The dye desorbed spectra of pure and Cu/N-doped TiO₂ nanoparticles. When compared to pure TiO₂, the absorption

peaks of N-doped TiO₂ were observed to be moved to the higher wavelength side. Due to the newly generated combined state, the introduction of Cu into the TiO₂ lattice resulted in a further apparent shift of the spectra towards the visible band. A noticeable absorption peak was detected, and this absorption increased with increasing Cu concentration up to a critical limit. Increased Cu addition may result in lower light absorption, increased band gap, and decreased particle size of TiO₂. Cu/N-doped TiO₂ NPs have a band gap of 1.0527 eV. These findings strongly show that Cu/N-doped TiO₂ NPs may efficiently react to visible light irradiation.

Fig. 5.6: UV-Vis Absorption spectroscopy for Cu/N co-doped TiO₂

5.7 THERMOGRAVIMETRIC ANALYSIS (TGA) for Cu/N co-doped TiO₂ and MWCNT@rGO :

TGA analysis was used to investigate the thermal behaviour and stability of as-prepared samples. Fig. 5.7 depicts the thermograms of T, NCuT, and NCuTFC catalysts. As can be observed, T and NCuT TGA thermograms indicated weight loss of 3.43, 3.81, and 7.94%, respectively, in the temperature range of ambient to 200°C, which is attributed to evaporation of water molecules and other volatile chemical reagents utilised during the synthesis process. When compared to the T pattern, the NCuT profile shows a significant weight loss at temperatures over 200 °C, which may

be attributed to the oxidation remnant contents of copper nitrate, which was employed as a source of Cu throughout the production procedure [35]. The oxidation process of copper nitrate is represented by the following equation: $\text{CuO(g)} + 2\text{NO}_2\text{(g)} + \text{O}_2\text{(g)} = \text{Cu(NO}_3)_2$. NCuTFC's thermogram pattern shows two areas of weight reduction. The initial loss of 7.94% up to 200°C was attributed to moisture removal from the catalyst surface and evaporation of other solvents utilised during the synthesis process. Interestingly, the initial step in the NCuTFC pattern is greater than in the NCuT and T patterns. Because the SBET area of NCuTFC was much greater than that of CNT and T, the concentration of physically adsorbed water molecules on the surface of NCuTFC sonophotocatalyst is higher than the others. The second weight loss of 15.59% occurred at temperatures ranging from 200 to 800 °C, which corresponds to carbon combustion and CNT degradation. This finding shows that the CNT content of the NCuTFC nanocomposite is around 8%, which is near to the predicted weight percent of CNT (7.5%) employed in the synthesis procedure.

Fig. 5.7 : Thermogravimetric analysis for Cu/N co-doped TiO₂ and MWCNT@rGO

5.8 CURRENT VS VOLTAGE CURVES (I/V) for DSSC :

TGA analysis was used to investigate the thermal behaviours and stability of as-prepared samples. The thermograms of T, NCuT, and NCuTFC catalysts are shown in Fig. 5.7. As can be observed, T and NCuT TGA thermograms indicated weight loss of roughly 3.43, 3.81, and 7.94%, respectively, in the temperature range of ambient to 200C, which is attributed to the evaporation of water molecules and other volatile

chemical reagents utilised during the synthesis process. When compared to the T pattern, the NCuT profile shows a significant weight loss at temperatures over 200 oC, which is attributed to the oxidation remnant contents of copper nitrate, which was utilised as a source of Cu throughout the production procedure [35]. The oxidation process of copper nitrate is represented by the equation below:
$$\text{Cu(NO}_3)_2 \rightarrow \text{CuO(g)} + 2\text{NO}_2\text{(g)} + \text{O}_2\text{(g)}$$
 NCuTFC's thermogram pattern shows two areas of weight decrease. The initial loss of 7.94% up to 200°C was attributed to moisture removal from the catalyst surface and evaporation of the other solvents utilised during the synthesis process. Surprisingly, the initial step in the NCuTFC pattern is greater than in the NCuT and T patterns. Because the SBET area of NCuTFC was much greater than that of CNT and T, the concentration of physically adsorbed water molecules on the surface of NCuTFC sonophotocatalyst was higher than the others. The second weight loss of 15.59% occurred at temperatures ranging from 200 to 800 oC, corresponding to carbon combustion and CNT breakdown. This finding shows that the content of CNT loaded in the NCuTFC nanocomposite is about 8%, which is similar to the predicted weight percent of CNT (7.5%) employed in the synthesis process.

(A)

(B)

(C)

(D)

Fig. 5.8 : Photovoltaic performances of Solar cells I/V curves

CHAPTER 6

SUMMARY AND CONCLUSION

In the present work, a novel core-shell ¹MWCNT@rGONR heterostructure was created and employed as the CE catalyst for a DSSC. The core of the carbon nanotube may be seen on a MWCNT in a TEM picture of MWCNT@rGONR. Nyquist graphs of the corresponding circuit's ¹symmetric cell with GNP, MWCNT, and MWCNT@rGONR, produced at zero bias potential. ¹According to photocurrent density–voltage curves of the DSSCs with CEs containing s-Pt and MWCNT@rGONR, recorded at 100 mW cm², the former is nearly completely changed into the latter. The rGONR shell has a low density of defects, which suggests a strong electron transport favouring

MWCNT@rGONR. These carbonaceous materials include pure MWCNT, pristine GNP, and heterostructures of MWCNT@rGONR. has the most surface area and roughest surface, as determined by SEM and RAMAN, respectively. Compared to cells with films of GNP (4.86%) and MWCNT (5.93%), the DSSC with the catalytic film of MWCNT@rGONR on its CE and sensitised with YD2-o-C8 dye exhibits the greatest efficiency (of 6.91%). The MWCNT@ rGONR cell's is similar to the s-Pt cell's CE value of 7.26 percent. The maximum electrocatalytic ability of the film for the reduction of I³ ions and its lowest charge transfer resistance at its electrolyte interface serve to justify the best performance of the cell with the film of MWCNT@rGONR. In a nutshell, inexpensive MWCNT@rGONR may be a material for replacing the conventional, expensive Pt in a DSSC . By using the sol-gel method, we created pure TiO₂ and Cu/Ndoped TiO₂ NPs with various Cu contents and effectively incorporated them in DSSCs. Adding the right quantity of Cu to TiO₂ .By increasing visible absorption and reducing band gap values, 2, might successfully change its optical and electrical characteristics. Additionally, the Cu/N-doped TiO₂ NP traces showed stabilised crystal structure, increased specific surface area, increased dye loading, improved charge transfer, and decreased charge carrier recombination. The greatest power conversion efficiency of a DSSC made with a 0.3 mol% Cu/N-doped TiO₂ photoanode was 11.70%, which is a significant increase (by around 41%) over the previous power conversion.

Overall, the DSSC built with these materials exhibits good efficiency, stability, and photoelectric performance, making it a suitable contender for future photovoltaic

applications. Further material and device structural optimisation may increase the DSSC's overall efficiency and stability.

Construction of DSSC using Nanostructured Cu/N co-doped TiO₂ Photoanode and MWCNT@rGO as Counter electrode using Phenothiazine derived organic Photosensitizer.

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