

Optical Study of Sol-Gel Derived TiO₂ Modified with Silver Nanoparticles for Photovoltaic Applications

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Abstract

This research explored the optical properties of sol-gel derived titanium dioxide (TiO₂) modified with silver nanoparticles (AgNPs) and its implications for photovoltaic applications. Through experimental procedures involving the synthesis of TiO₂ and the incorporation of silver nanoparticles, it was demonstrated that modifying TiO₂ with AgNPs enhances its optical characteristics. According to an analysis of the data, there was no discernible peak in the visible and near-infrared portions of the TiO₂ absorption

spectra. Nonetheless, a significant peak in the UV area was seen at 430 nm with an absorbance value of roughly 1.2. The reason for this peak is the movement of electrons within the produced molecular material between molecules with mild ionicity. The study also discovered that the biologically produced AgNPs had a wide absorption band beginning at about 380 nm in their UV-visible spectra. The surface plasmon resonance effect is responsible for this. The reaction solution's

color shifted from light brown to dark brown during the reduction phase, signifying the creation of AgNPs. This color shift is caused by a redox reaction in which active chemicals in the kola pod extract reduce silver ions (Ag^+) to metallic silver nanoparticles (Ag_2).

The investigation also reveals that all TiO_2 and TiO_2 coated with one, two, and three cycles of AgNPs showed good transparency in the near-infrared and visible regions, whereas the ultraviolet region showed a dramatic decline. Both coated and pure TiO_2 samples have comparatively high optical reflectance.

Key Words:

Titanium Dioxide (TiO_2), Silver Nanoparticles (AgNPs), Sol-Gel Synthesis, Optical Properties

1 Introduction

With the increase of population, technological and economic development, human beings need more energy to create a better life environment. However, burning traditional fossil fuels is causing a series of environmental problems, such as climate change, global warming, air pollution and acid rain (Peng *et al.*, 2013; Bhattacharya *et al.*, 2014; Tyagi *et al.*, 2013).

In order to address the political, economic, and environmental issues associated with producing power, it is imperative that renewable energy solutions be developed. The emergence of such energies has significantly increased the interest of researchers, politicians, and business executives in comprehending the economic feasibility of the new energy source (Bhattac). One of the most promising markets in the field of renewable energy is the capture of solar energy using photovoltaic panels to generate electricity. The photovoltaic sector is currently increasingly contentious globally, particularly in Europe, China, and the US, because to its rapid development prospects and high levels of investment. Brazil is beginning to make significant progress, particularly after (Bhattac Capturing solar energy through photovoltaic panels, in order to produce electricity is considered one of the most promising markets in the field of renewable energy. The photovoltaic sector is currently increasingly contentious globally, particularly in Europe, China, and the US, because to its rapid

development prospects and high levels of investment. In Brazil, the advances are starting to be significant, especially after the insertion of solar energy in Brazil's energy matrix, and the start of solar energy auctions during a period when the energy industry is struggling because of the decrease of hydroelectric energy, which is presently Brazil's primary energy matrix, and the rise in power costs (Kim *et al.*, 2014).

As the globe struggles with the issues of climate change and energy sustainability, the search for renewable energy sources has accelerated in recent years. Solar energy is particularly notable among these renewable sources due to its availability and capacity to supply the world's energy needs. Photovoltaic (PV) technology, which converts sunlight directly into electricity, plays a crucial role in harnessing solar energy. The investigation of new materials and manufacturing processes becomes crucial as scientists work to improve the effectiveness and cost of PV devices (Kim *et al.*, 2014).

Titanium dioxide (TiO_2) has emerged as a promising material for photovoltaic applications due to its favorable optical and electronic properties, abundance, and environmental compatibility. In particular, TiO_2 -based solar cells have garnered significant attention owing to their high stability and low cost. However, to realize their full potential, improvements in the efficiency of TiO_2 -based solar cells are essential (Al Saleh, A. M. 2025).

Development of new nanomaterials with metal nanoparticles (Ag, Au, Cu, Rh, Pd, etc.) deposited on oxide surfaces, embedded within pores or encapsulated in its matrices have gained much attention in material science because of expanding applications of such composites in optics, medical diagnostics, analytical chemistry, catalysis, photo-catalysis etc. The most widely used catalyst is titanium dioxide. Titania effective properties could be improved by mixing with other oxides (ZrO_2 , SiO_2 , ZnO) that act as additives to control structure-sorption, optical and electronic properties. Incorporation of metal nanoparticles into a solid matrix of titania enhances their quantum efficiency (Kim *et al.*, 2001; Alberius, 2002). Semiconductor-metal composite nanoparticles have been shown to facilitate charge rectification in the

semiconductor nanostructures that is beneficial for maximizing the efficiency of photocatalytic reactions (Kamat, 2003, Subramanian *et al.*, 2001). The metal NPs, being adsorbed or incorporated into titania matrix, modify the interface and/or alter the pathways with which photo-generated charge carriers undergo recombination or surface reactions. Metal nanoparticles embedded in dielectric matrixes are promising composite materials for optical applications as systems with enhanced third-order electronic susceptibility. (Gao, C., Lyu, F., & Yin, Y. 2020)

The sol-gel techniques are most effective and popular on preparation of metal/oxide or metal/organics nanocomposites (Chan *et al.*, 2004; Epifani *et al.*, 2000; Gonella *et al.*, 1999; He J. *et al.*, 2003; He C. *et al.*, 2002; Liz-Marzan *et al.*, 1996; Kelly *et al.*, 2003; Kreibig and Vollmer, 1995; Shacham *et al.*, 2004; Shter *et al.*, 2007; Song *et al.*, 2005; Traversa *et al.*, 2001). However, it is not analyzed in the literature the interrelation of the synthetic conditions and physicochemical properties of obtained materials, and hence the recommendations for the preparation of effective stable photo-catalyst based on titania films and modified with small amount of noble metal nanoparticles (NPs).

Adding silver nanoparticles (Ag NPs) to TiO₂ is a viable way to improve its performance in solar devices. Localized surface plasmon resonance (LSPR), one of silver nanoparticles' special optical and electrical characteristics, can be used to improve light absorption and charge carrier generation in solar cells. Ag NPs can be included into TiO₂ matrices to provide materials with better charge transport and light collecting capabilities, which will increase photovoltaic systems' overall efficiency (Tyagi *et al.*, 2013).

A flexible and economical method for creating TiO₂-based materials with customized compositions and morphologies is sol-gel synthesis. Because of their high surface area, porosity, and adjustable characteristics, sol-gel produced TiO₂ films have shown impressive potential for usage in solar cells. Silver nanoparticles can be incorporated into sol-gel-derived TiO₂ matrices to produce composite materials with complementary optical and electrical characteristics that are perfect for

solar energy applications. (Peng *et al.*, 2013). harya *et al.*, 2014; Kim *et al.*, 2014).

Literatue Review

Photovoltaic Devices

Nano-micro-structured thin-film solar cells (SCs) under advanced light management designs have attracted intensive attention due to their potential in realizing cost-effective solar energy utilization (Jeon *et al.*, 2015; Green *et al.*, 2015). These devices exhibit thermal effects such self-heating and light-induced heating, which can cause the device to overheat and significantly reduce output performance (Broderick *et al.*, 2015; Ghani *et al.*, 2015). Temperature increases under high concentration ratios (e.g., 1000 suns) will pose a significant challenge to maintaining the operation stability of SCs, particularly for concentrating photovoltaics. As a result, the SC performance is significantly influenced by temperature impacts.

In addition to providing a comprehensive grasp of the multi-domain photovoltaic physics, taking this significant mechanism into account opens up a plethora of new application opportunities. For instance, Fan's group's passive radiative cooling has shown promise in cooling SCs for increased photo-conversion efficiency (Raman *et al.*, 2014; Zhu *et al.*, 2014). As a result, it is clear that photovoltaic devices are typical thermodynamic systems in addition to optical and electrical systems; these three physical domains are closely related.

Prior SC simulations have mostly addressed electromagnetic and electrical responses using optoelectronic analysis. (Li *et al.*, 2013; Li *et al.*, 2011; Li *et al.*, 2015; Shang *et al.*, 2015) which not only maximize light absorption but also ensure that the generated carriers can be efficiently collected. For example, coupled optical and electrical modeling of nanostructured SCs was reported to simultaneously increase the light absorption and optimize the electrical properties of α -Si:H cell (Deceglie *et al.*, 2012). A thorough optoelectronic simulation has been conducted for nanowire and nanohole SCs, revealing that nanowire and nanohole SCs have a superior light harvesting capability than planar devices and that radially doped SCs are more efficient for carrier collection than axially doped systems (Shang *et al.*, 2015). However,

previous optoelectronic studies are performed with the assumption that SCs are operating under standard test condition (STC), (Nelson, 2003; Kucharski *et al.*, 2011) where the air mass index is 1.5, the solar irradiance $P_s = 1000 \text{ W m}^{-2}$, and the ambient temperature $T_{amb} = 25 \pm 1 \text{ }^\circ\text{C}$. Moreover, the operating temperature of SCs (i.e., T) is set to be equal to T_{amb} by affect the output performance (Chander *et al.*, 2015). To advance knowledge of SCs and investigate innovative photovoltaic designs for high efficiency and high stability, a comprehensive treatment of the optoelectronic and thermodynamical response in the spatial and frequency domains is highly sought. With over 59GW of solar PV deployed in 2015, photovoltaic energy is still expanding. Although Si wafers accounted for 93% of PV production, the proportions of CdTe and CI(G)S are both increasing. Additionally, OPV and dye-sensitized solar cells continue to advance at the laboratory level. Reducing the cost of systems and modules is becoming more and more important as the industry expands.

2.2 TiO₂ Thin Films Made using The Sol-Gel Process

Sol-gel-synthesised titanium dioxide (TiO₂) thin films are essential for several technological uses, including as environmental remediation, photocatalysis, and photovoltaics (Bertoluzzi *et al.*, 2021). In the sol-gel process, a liquid sol is changed into a gel, which is subsequently heated to form a solid film. Because of its ease of use, affordability, and capacity to create films with exact control over composition and thickness, this technique is preferred (Fujishima and Honda, 2021).

In the sol-gel preparation of TiO₂ films, titanium alkoxides like titanium tetraisopropoxide (TTIP) are hydrolyzed and condensed in a solvent, typically ethanol (Khan *et al.*, 2020). The pH of the solution is adjusted, usually with acids or bases, to control the gelation process and influence the morphology of the final film. This process allows for the synthesis of TiO₂ films with tailored properties by modifying parameters such as solvent concentration, pH, and temperature (Wang *et al.*, 2022).

TiO₂ films are placed onto substrates utilizing methods including spin coating and dip coating after sol preparation. For creating

consistent, thin layers of TiO₂, spin coating works especially well (Smith *et al.*, 2022). The films are then subjected to annealing at high temperatures, typically between 400°C and 600°C, to achieve crystallization. This heat treatment is essential for converting the amorphous gel into crystalline TiO₂, which is critical for optimizing the film's performance in various applications (Zhou *et al.*, 2023).

The annealing process results in the formation of different TiO₂ polymorphs—anatase, rutile, and brookite each with distinct properties. Anatase is known for its high photocatalytic activity, while rutile provides better chemical stability (Kumar *et al.*, 2021). By controlling the annealing conditions, such as temperature and duration, researchers can selectively produce these phases to suit specific applications, from environmental cleanup to energy harvesting. (Eddy, D. R *et al.*, 2023).

Moreover, the sol-gel method allows for the incorporation of dopants or nanoparticles into TiO₂ films to enhance their properties. For instance, adding silver or other metal nanoparticles can improve photocatalytic activity or alter optical characteristics, making TiO₂ films more versatile for various applications (Pereira *et al.*, 2021). One of the main benefits of the sol-gel process is its adaptability, which makes it possible to create sophisticated materials with improved functions.

TiO₂ thin films made using the sol-gel method are characterized using a variety of methods to evaluate their surface, optical, and structural characteristics. The crystallographic phases are examined using X-ray diffraction (XRD), and the surface shape is shown in detail by scanning electron microscopy (SEM). (Xie *et al.*, 2021). Optical properties, including absorption and photoluminescence, are evaluated using UV-Vis spectroscopy and photoluminescence spectroscopy to understand the film's performance in various applications (Zhang *et al.*, 2022).

TiO₂ thin films produced by the sol-gel method have shown remarkable performance in applications such as photocatalysis, where they are employed to degrade organic pollutants under UV light (Hoffmann *et al.*, 2021). In photovoltaics, these films are used as photoanodes in dye-sensitized solar cells (DSSCs), where their properties are crucial for efficient light absorption and charge separation

(Lee *et al.*, 2021). The sol-gel method's ability to tailor TiO₂ film properties makes it an invaluable technique for advancing these technologies.

The sol-gel process offers a strong and flexible way to create TiO₂ thin films with customized characteristics for a variety of uses. By controlling synthesis parameters and incorporating various dopants or nanoparticles, researchers can optimize these films for use in environmental and energy-related technologies, demonstrating the method's ongoing relevance and versatility (Rao *et al.*, 2022).

2.3 Sol-Gel Process

The process of sol-gel has been intensively investigated and used in recent years. The most important factors affecting its wide application are that the method is relatively easy rather than other coating processes and it provides a good enhancement for metallic biomaterial coating layers on the substrate (Zhang *et al.*, 2011; Koutsopoulos, 2002 Danks *et al.*, 2016). In order to prepare the solution (sol) part, usually calcium and phosphorus, as CaP precursors, are used while followed by addition of two common solvents like distilled water and pure ethanol (Costa *et al.*, 2012; Combes and Rey, 2010; Cardoso *et al.*, 2012). Mostly, ethanol is used to dissolve phosphorous precursors in shape of phosphorus pentoxide or triethylphosphite while addition of a minute amount of water is the next step to increase the hydrolysis of the produced sol (Kessler *et al.*, 2006). Similarly, for solving the calcium part which is mostly in shape of calcium nitrate, ethanol is the first option and the resulted solution is added in controlled drops to the hydrolyzed phosphorous solution (Agrawal *et al.*, 2011). Lastly, refluxing causes the solution obtained in the preceding step to evaporate the solvent at various temperatures. This procedure is repeated until the solution reaches the desired viscosity, at which point it is no longer a low viscosity solution and is referred to as sol-gel. The key factors influencing the temperature required for apatite production and the associated chemical activity are the precursors' chemical makeup. (Shadanbaz *et al.*, 2012; Dorozhkin, 2014; Mehta *et al.*, 2018; Budd *et al.*, 1985; Amerinatanzi *et al.*,

2017; Amerinatanzi *et al.*, 2016; Zamanian, 2017).

2.4 Sol-Gel Applications

The sol-gel process has become a popular technique for creating materials with a variety of uses, such as powders, composites, and thin films. This method, which includes turning a solution (sol) into a solid gel phase, has a number of benefits, including the capacity to cover intricate forms, fine composition control, and low processing temperatures.

Recent research has underscored the evolution of sol-gel applications in thin films, composites, and powders amongst others. In thin films, developments in nanostructured and hybrid films are enhancing functionalities such as self-cleaning and superhydrophobic properties (Garcia and Brown, 2023). For composites, the focus has shifted to incorporating advanced nanomaterials like graphene and carbon nanotubes to push the boundaries of mechanical strength and conductivity (Kim *et al.*, 2023). In powder technology, there is a trend towards developing more environmentally friendly sol-gel processes and materials with enhanced properties for energy and environmental applications (Li *et al.*, 2024).

The sol-gel process's adaptability has enabled significant technological advancements across various industries. Sol-gel-derived thin films and powders are essential for the creation of next-generation electronics devices and sensors. Sol-gel composites are used in the automotive and aerospace industries to create stronger, lighter materials that improve overall performance and fuel efficiency. The widespread use of sol-gel-derived materials reflect the process's impact on modern technology, providing cost-effective and scalable solutions for complex manufacturing challenges.

2.4.1 Thin Films

Because sol-gel technology can produce high-quality coatings with regulated thickness and composition, it has had a considerable impact on the development of thin films. Sol-gel thin films are used in a variety of applications, such as barrier layers, optical coatings, and anti-reflective coatings. The goal of recent developments in sol-gel-derived thin films is to improve these coatings' durability and

performance. For example, studies have demonstrated the creation of transparent conductive oxides and functional coatings that enhance solar cell and display technologies' efficiency (Lee et al., 2023). These films can be precisely deposited on substrates using the sol-gel technique, allowing for the creation of multi-layered structures with customized optical and electrical characteristics.

2.4.2 Composites

By enabling the molecular integration of organic and inorganic elements, sol-gel technology has also transformed the field of composites. The sol-gel process makes it easier to incorporate fibers or nanoparticles into a matrix, producing composites with improved electrical, mechanical, and thermal characteristics. The creation of sol-gel-derived nanocomposites for usage in the automotive, biomedical, and aerospace industries has been the subject of recent research. (Smith and Zhang, 2022). These composites benefit from the sol-gel process's ability to uniformly disperse nanoparticles within the matrix, improving the overall performance and functionality of the composite materials.

2.4.3 Powders

In materials science, the sol-gel method of producing powders is very advantageous, especially for applications in electronic devices, ceramics, and catalysis. Powders made from sol-gel have a consistent particle size distribution and high purity, both of which are essential for the functionality of advanced materials. Sol-gel processing has recently led to the creation of sophisticated ceramic materials and high-performance catalysts. For instance, the production of powdered nanoparticles for catalytic uses has been refined to improve selectivity and reaction speeds. (Chen et al., 2024). Additionally, sol-gel-derived powders are being explored for their use in advanced energy storage systems, where their fine control over particle size and composition can lead to improved performance.

2.5 Silver Nanoparticles and their Optical Properties

Silver nanoparticles (AgNPs) are metallic particles that range in size from 1 to 100 nanometers. They have distinct optical

characteristics that set them apart from bulk silver. These characteristics result from the interaction of light with the free electrons on the nanoparticles' surface, a process called surface plasmon resonance (SPR) (Babaei and Karami, 2020). SPR is the result of significant light absorption and scattering at particular wavelengths caused by collective electron oscillations caused by incoming light. AgNPs are extremely beneficial in a variety of domains, including as sensing, imaging, and medicine, because of this feature (El-Sayed, 2019).

AgNPs' strong absorption in the visible portion of the electromagnetic spectrum is one of their most remarkable optical characteristics. The SPR effect, which is extremely sensitive to the size, shape, and surrounding environment of the nanoparticles, is responsible for this absorption (Huang et al., 2021).

For example, spherical AgNPs typically exhibit a prominent absorption peak in the range of 400-450 nm, which can shift depending on the particle size and aggregation state (Jin et al., 2018). This tunability of optical properties allows for the customization of AgNPs for specific applications.

The shape of AgNPs also significantly influences their optical characteristics. While spherical nanoparticles have a single SPR peak, other shapes such as rods, triangles, or cubes exhibit multiple absorption peaks corresponding to different plasmonic modes (Ahsan et al., 2022). For instance, silver nanorods show two SPR peaks: one along the long axis and another along the short axis, making them useful for applications requiring precise optical responses (Sanniccolo et al., 2020). These shape-dependent properties enable the fine-tuning of optical features for applications such as biosensing and imaging. The surrounding medium and environment also affect the optical properties of AgNPs. When AgNPs are dispersed in different solvents or attached to biological molecules, changes in the local refractive index can shift the SPR peak and alter the absorption and scattering characteristics (Noguez, 2007). This sensitivity to the local environment is exploited in sensing applications, where AgNPs can detect changes in the surrounding

medium, such as the presence of specific biomolecules or environmental pollutants (Zhao *et al.*, 2021).

In addition to their SPR properties, AgNPs exhibit unique fluorescence characteristics that can be utilized in imaging and diagnostic applications. When excited at specific wavelengths, AgNPs can emit light at different wavelengths, providing a means for multiplexed detection and imaging (Chen *et al.*, 2022). AgNPs are frequently coupled with fluorophores or quantum dots to augment this fluorescence, which can greatly boost emission intensity and improve signal-to-noise ratios in imaging applications. AgNPs' optical characteristics can also be altered by functionalization and chemical changes. Researchers can improve AgNPs' stability, solubility, and interaction with biological targets by affixing various ligands or functional groups to their surface. (Baker *et al.*, 2019). This functionalization not only improves the practical utility of AgNPs in various applications but also allows for the precise control of their optical properties, such as the wavelength of SPR peaks.

Because of their optical characteristics, silver nanoparticles are also being investigated for their potential in medicinal applications. For instance, photothermal therapy, which uses localized heating of AgNPs caused by laser irradiation, can be employed for targeted cancer treatment (Huang *et al.*, 2020). AgNPs' effective light absorption causes localized heating, which can kill cancer cells while causing the least amount of harm to nearby healthy tissue.

The unique optical properties of silver nanoparticles, driven by surface plasmon resonance, make them highly versatile for a range of applications. Their intense visible light absorption, shape-dependent optical characteristics, and sensitivity to the local environment enable their use in sensing, imaging, and therapeutic fields. Advances in the synthesis and functionalization of AgNPs continue to expand their potential applications, highlighting their significance in modern science and technology (Liao *et al.*, 2021).

2.6 Optical properties

The following are the optical properties used in the research of this work

1. Optical Absorbance (A) : This is the measure of the amount of light absorbed by a material.

$$A=1-(T+R) \quad (2.1)$$

2. Optical Transmittance(T): It is the amount of light passes through a material

$$T=1-(A+R) \quad (2.2)$$

3. Optical Reflectance (R): It is the amount of light that is reflected by a material

$$R=1-(A+T) \quad (2.3)$$

Some of the optical characteristics of a material that were not utilized in this research project are listed below, but they can be used to examine a material's optical characteristics.

4. Refractive index (n): It is the phenomenon of light beam to bend when passing from one medium of varying density to another.

$$n = \frac{1+\sqrt{R}}{1-\sqrt{R}} \quad (2.4)$$

5. Photon Energy (E): is the energy carrier by a single photon which is a quantum of electromagnetic radiation. (2.5)

$$E=hf = \frac{hc}{\lambda}$$

3. Materials and Method

3.1 Materials

In this investigation, the following resources were used:
"Ti-Nanoxide Tsp-36; Methanol; Tin II Chloride; Aceton I; Ammonium Hydroxide; Silver Nitrate; Sodium Hydroxide; Concentrated Tetraoxosulphate VI Acid; Fluorine Doped Tinoxid (FTO); Hydrochloric Acid; Titanium Tetrachlorote; Butyrolactone; Dimethyl Sulfoxide; Sodium Laureth Sulphate; Frosted Glass Methanol and Ethanol; Titanium Isopropoxide; Titanium Nanoxide; Acetyl Acetone; Zirconium Nanoxide; TiO2 Paste; Elcocard; P25 Titania

3.2 Equipments

The following are the main equipment used in this study:

- Muffle Furnace
- UV-ViS-NTR Spectrophotometer
- Electric Hand Engraver
- Magnetic Stirrer Plate
- Sonicator
- Dektac 150 Surface Profiler
- Keithley 250 Source Meter
- Hot Plate
- Beakers

- Sharp Tweezers
- Glass Knife
- Air Dryer
- XRD

3.3 AgNP Biosynthesis

We reduced the Ag ions by adding 1 ml of the pod extract to 40 ml of a 1 mM AgNO₃ solution in order to create the biogenic AgNPs. At room temperature, the reaction was carried out for two hours. UV-Vis spectroscopy and virtual color changes were used to observe the silver nanoparticles. In our synthesis, the colanitida extract served two purposes: first, it was employed as a reducing agent for the biosynthesis of AgNPs, and second, it was employed as a capping agent to keep the nanoparticles from coming into direct contact with one another for improved device performance.

3.4 Synthesis of Compact TiO₂

The compact Titanium was obtained following a modified method of sol-gel process, where 2.1 g of P25 Titania (Dagusta) was dispersed in 12 ml distilled water with 0.3 mol of non-ionic surfactant (Triton-X 100) and 0.5 g acetaldehyde, then set into vibration with the aid of a magnetic stirrer for 24 hours. (Danladi, E. et al 2023).

3.5 Preparation of Methyl Ammonium Lead Tri-Iodide Perovskite (MAPbI₃) Precursors

Precursor A (PbI₂): 4.6 g of lead iodide (PbI₂) was mixed with dimethylformamide. This mixture was cooked in a bath of molten wax at 2500C for 45 minutes. Precursor B (MAD): 20 ml of dry isopropanol and 0.3 g of methyl ammonium iodide were mixed, and the mixture was shaken for three minutes to achieve equilibrium with no white residue left.

3.6 Preparation of the Photo-anodes

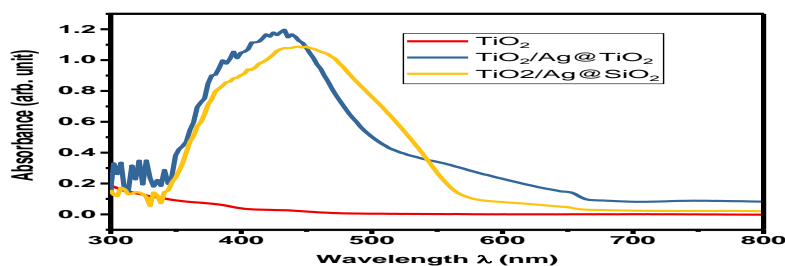
Fluorine doped Tin Oxide (FTO), a transparent conductive oxide with a sheet resistance of 15

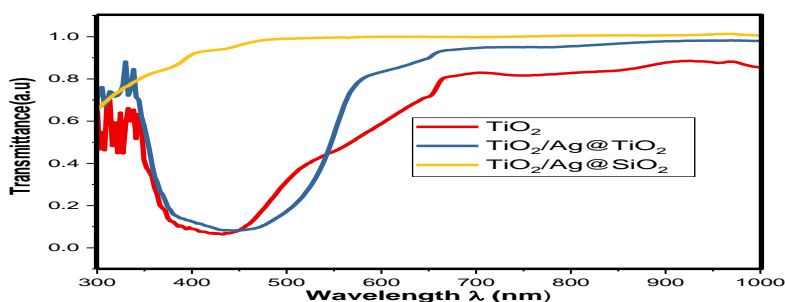
Ω square-1, was cleaned using sodium laureth sulfate. On the FTO, the compact titanium (c-TiO₂) layer was dynamically spin-coated for 20 seconds at 4000 rpm. After being dried for ten minutes at 1200C, it was annealed for thirty minutes at 4500C. Using spin coating, the m-TiO₂ was applied to the c-TiO₂ for 20 seconds at 4000 rpm.

A few drops of the prepared Precursor A were dynamically spin-coated for the controlled device, followed by the identical procedure for Precursor B. After the formation of a dark perovskite layer, any excess MAI was removed by immersing it in a beaker of dry propanol for five minutes. After that, the glass/FTOc-TiO₂/m-TiO₂/MAPbI₃ composite was annealed for ten minutes at 1200C. Next, spin coating was used to form an inorganic Hole Transport layer (CuI) on the layer, which was then annealed at 1500C. One cycle of biosynthesized AgNPs was applied to the c-TiO₂ composite for the second device. After that, the glass/FTOc-TiO₂/m-TiO₂/AgNPs composite was heated to 2000C for five minutes. The MAI precursor was then quickly spin-coated in the same way as with the first device after a few drops of the prepared PbI₂ were aggressively spin-coated. Following that, a spin coating process was used to form an inorganic Hole Transport layer on the layer, which was then annealed at 1500C. This leads to the glass/FTOc-TiO₂/m-TiO₂/1cycle-AgNPs/MAPbI₃/Cul photoanode architecture. After two and three cycles of AgNPs were deposited, the third and fourth devices underwent the identical procedure as the first. This resulted in glass/FTOc-TiO₂/m-TiO₂/2 cycles-AgNPs/MAPbI₃/Cul and glass/FTOc-TiO₂/m-TiO₂/3 cycles-AgNPs/MAPbI₃/Cul designs.

Results and Discussion

The results for the optical study of sol-gel derived TiO₂ modified with silver nanoparticles for photovoltaic applications are shown below





Figures 4.1 and 4.2 show optical absorbance and transmittance, respectively.

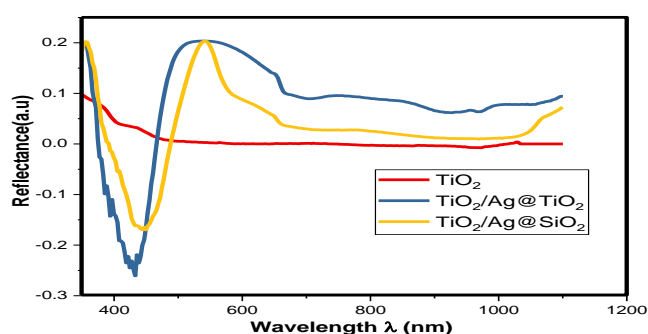


Figure 4.3: Optical Reflectance

4.2 Discussion

The absorbance-wavelength plot of TiO_2 , AgNPs, and TiO_2 with AgNP coating cycles is displayed in Figure 4.1. According to the TiO_2 spectrum, there was no discernible absorption peak in the visible or near-infrared range, but there was a significant peak in the UV range between 400 and 500 nm at an absorbance value of 1.2. The transfer of electrons between molecules with a modest ionicity along the synthesized molecular material is what causes this peak. This clearly implies that TiO_2 must be modified in order to become active at longer wavelengths (visible and near-infrared area).

The surface plasmon resonance effect is responsible for the broad band in the biologically produced AgNPs' UV-visible spectrum that starts at 380 nm. This is because the reduction of the silver ions in the solution causes nanoparticles to nucleate and grow. During the reduction process, the reaction solution's color shifts from light brown to dark brown, signifying the creation of AgNPs. This color shift results from the active chemicals in

the kola pod extract participating in a redox reaction of silver metal Ag^+ ions in silver Ag0 nanoparticles. SPR excitation is indicated by this color.

Free electrons in metal nanoparticles create an SPR absorption band as a result of the electrons' mutual oscillation in resonance with the light wave. The peak's appearance demonstrates the silver nanoparticles' surface plasmon resonance characteristic. The optical transmittance of pure TiO_2 and TiO_2 coated with cycles of AgNPs is displayed in Figure 4.2. The visible and near-infrared regions of all the samples exhibit high transparency, but the ultraviolet region exhibits a dramatic decline. Transmittance increased with TiO_2 without AgNPs, suggesting that AgNP coating on TiO_2 increases film porosity, which in turn increases transmittance. This may be the cause of the optical film density's decline when AgNP cycles increase. The increase in AgNPs cycles caused the film to become denser, which impacted transmission and led to high transparency. The observed differences in the

transmittance of the film are caused by surface flaws, which result in variations in surface morphology, crystal size, and transmittance to lightscattering.

The optical reflectance of pure TiO₂ and TiO₂ coated with different AgNP cycles is displayed in Figure 4.3.

The films were found to be comparatively reflective, as the stories demonstrate. As the number of AgNP cycles increased, the reflectance was observed to decrease. The increase in roughness is responsible for the reflectance's gradual rise from 400 nm to a maximum peak at 540 nm before it displays a peak and valley. The films' porosity increased with the addition of AgNPs cycles, which also caused the reflectance to drop.

5. Conclusion and Future Scope

5.1 Conclusion

This research has successfully explored the optical properties for sol-gel derived titanium dioxide (TiO₂) modified with silver nanoparticles (Ag NPs) and its implications for photovoltaic applications. Through a series of experimental procedures, including the synthesis of TiO₂ and the incorporation of silver nanoparticle, we have demonstrated that the modification of TiO₂ with Ag NPs significantly enhances its optical characteristics. The introduction of silver nanoparticles to the TiO₂ matrix was found to increase the absorption spectrum, particularly in the visible range. This improvement is ascribed to Ag NPs' localized surface plasmon resonance (LSPR) effect, which improves solar spectrum utilization. Increased activity of photocatalysis: the study also evaluated the photocatalytic performance of the modified TiO₂ under light illumination, with results showing a significant enhancement in degradation rates of organic pollutants, illustrating the practical applicability of Ag-TiO₂ composites. Stability and durability: For commercial photovoltaic applications, the produced Ag-TiO₂ composites showed good stability over time. The results show that Ag-modified TiO₂, which can significantly improve solar energy collecting and conversion capacities, can be synthesized using the sol-gel method.

5.2 Future Scope

- Several suggestions for further research and useful applications can be offered in light of the findings of this study:
 - Silver content optimization: Although this study highlighted the advantages of incorporating Ag NPs, future research should concentrate on determining the optimal ratio of silver nanoparticles to produce maximum optical and photovoltaic performance without potentially causing agglomeration problems.
- Investigating other nanoparticles: future studies could explore the effects of different types of metal nanoparticles, such as gold (Au) or copper (Cu), or even combination of metals, to further investigate how these modifications might enhance the properties of TiO₂.
- Long-term stability tests: conducting long-term stability and performance testing of Ag-TiO₂ composite under real-world conditions to assess how environmental factors affect the material's properties and efficiency over time.
- Integration into photovoltaic devices: future work should focus on integrating the modified TiO₂ into actual photovoltaic devices to evaluate their performance in practical applications, including the assessment of device architecture, efficiency, and economic viability.

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