

Original Article

Sol-Gel Derived Ag-TiO₂ Thin Films for Photocatalytic Degradation of Azo Dye

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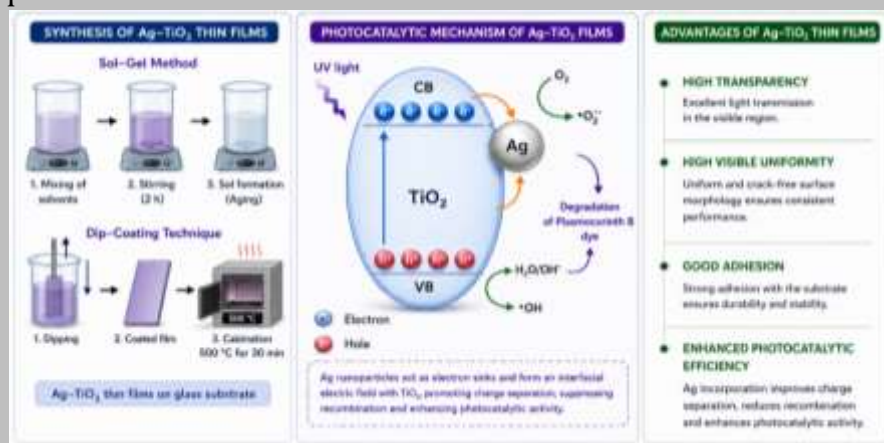


Abstract:

In this study, TiO₂ and Ag-TiO₂ thin-film photocatalysts were synthesized using the sol-gel dip-coating technique. The films were examined using X-ray diffraction (XRD), UV-Vis spectroscopy, and Fourier-transform infrared (FTIR) spectroscopy. According to the XRD data, anatase phase TiO₂ with a crystalline size of 10.49 nm was formed. The transmission spectra of the Ag-TiO₂ films show a slight redshift compared to pure TiO₂. FTIR spectroscopy revealed the formation of a TiO₂ network. The Ag-TiO₂ thin films exhibited considerably improved photocatalytic performance for Plasmocorinth B dye degradation compared to pure TiO₂ thin films. Ag-TiO₂ showed the highest photocatalytic activity at 1 at.% Ag concentration of degrading Plasmocorinth B by over 70% in 60 min upon UV exposure at a rate constant of 0.09 min⁻¹. This is a notable improvement over pure TiO₂, demonstrating the beneficial effects of adding silver, such as improved charge separation and increased photocatalytic activity. In addition, Ag-TiO₂ thin films show high visual homogeneity, transparency, and good adherence to the substrate, making them strong candidates for photocatalytic applications.

Keywords: Sol-gel method, dip-coating, Ag-doped TiO₂ films, photocatalysis.

Graphical Abstract:



Introduction:

Clean water is a major concern in modern society. Traditional wastewater treatment techniques, which encompass physical, chemical, and biological processes, frequently generate secondary pollutants and fail to effectively eliminate specific organic contaminants. To address these limitations, advanced oxidation processes (AOPs) are widely used [1]. AOPs generate highly reactive oxidizing species that degrade pollutants into less harmful and non-toxic products [2]. Common AOP techniques include ozonation, photocatalysis, Fenton reactions, ultrasonic irradiation, and electron beam irradiation, among which photocatalysis has been the most extensively studied [3]. Photocatalysis is a light-driven process that occurs in the presence of photocatalysts [4]. Upon light irradiation, electrons in the photocatalyst are excited from the valence band to the conduction band, creating electron-hole pairs.

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These charge carriers participate in redox reactions on the catalyst surface, producing reactive species responsible for pollutant degradation [5]. Various semiconductor materials, such as ZnO, TiO₂, WO₃, and SnO₂, have been commonly employed as photocatalysts. [6]. Titanium dioxide (TiO₂) is the most extensively studied material because of its remarkable photocatalytic efficiency, affordability, non-toxicity, and strong chemical stability [7-9].

Titanium dioxide (TiO₂) exists in three crystalline forms: anatase, rutile, and brookite. Among these, the anatase phase exhibits superior photocatalytic activity compared to the other two phases [10]. Various techniques have been employed to synthesize TiO₂ photocatalysts, including chemical vapor deposition, sol-gel, hydrothermal, solvothermal, electro-deposition, and microwave methods [11]. The sol-gel method is the most widely preferred method for producing thin films because it offers versatility, uniformity, straightforward synthesis, and reactions that occur under mild ambient conditions [12]. Various substrates, regardless of their size and shape, can be coated using the sol-gel technique. Additionally, substrates such as stainless steel plates, silica rings, glass wool, and glass slides can be deposited using this method [13]. The sol-gel technique can be categorized into sol-gel dip and spin coatings. In the current study, a dip-coating approach was employed to deposit the films. This process involves three stages. Initially, the substrate was immersed in the sol solution and allowed to remain submerged for a specific duration, facilitating the interaction between the substrate surface and the sol. In the second step, the substrate was withdrawn from the sol at a constant retrieval speed. In the final step, the solvent in the sol evaporates, forming a uniform, thin film on the substrate surface [14]. Although TiO₂ has great properties, it still has certain limitations, such as a very large band gap, high recombination rate, and activation under UV light. To improve its performance under visible light and reduce recombination, different methods have been used, such as doping with metals, nonmetals, and composite formation. Different noble metals, such as Pt, Ag, Ce, and Au, have been used as dopants in TiO₂, as they enhance the activity to some extent [15-17]. Silver is a widely used dopant because of its ability to create accumulation sites for electrons, which helps reduce the catalyst grain size, thereby increasing the specific surface area [18]. J.A. Borrego Pérez et. al. studied the photocatalytic degradation phenomenon of Ag-dispersed TiO₂ thin films of different wt. % synthesized using sol-gel spin coating method and annealed at 400 °C. They observed that the prepared Ag-TiO₂ was 60% more efficient than pure TiO₂ for the photocatalytic degradation of methylene blue [19]. Similarly, in another study by Komaraiah et al. Ag-TiO₂ films were synthesized on a glass substrate via the sol-gel spin-coating method with different percentages of Ag loading. They studied the photocatalysts for the decoloration of methyl orange and methylene blue. They observed that 5% Ag-TiO₂ exhibited good efficiency [20]. In this study, we report the photocatalytic degradation of the Plasmocorinth B dye using Ag-TiO₂ prepared using the sol-gel dip-coating method.

Materials and Experimental Methods:

Silver nitrate (Ag-N Fermont 99%), 2-Methoxy Ethanol, Titanium (IV) isopropoxide (99.99%), Ethyl Acetoacetate, Pluronic P123, Absolute Ethanol, Tetraethyl orthosilicate (98%), and Nitric Acid (68%) were purchased from Sigma Aldrich. The preparation of a silica (SiO₂) sol involved the use of tetraethoxysilicate (TEOS) as the starting material. The mixture included ethanol with a molar ratio of $n(\text{EtOH})/n(\text{Si})=6.47$, nitric acid at $n(\text{HNO}_3)/n(\text{Si})=0.44$, and water with $n(\text{H}_2\text{O})/n(\text{Si})=8.06$. The sol was made uniform by stirring the mixture for 2 h, after which it was used for film deposition through the dip-coating technique [21, 22]. Single-layer SiO₂ films were formed on glass substrates with calcination at 500°C for 30 min. This SiO₂ coated glass slide acts as a substrate for the deposition of TiO₂ thin films. SiO₂ has a dense structure that acts as an effective barrier to prevent the migration of Na⁺ ions into the TiO₂ lattice during heat treatment. Hence, it avoids the detrimental effect on the photocatalyst performance.

For the preparation of the titania sol, titanium precursor (TiP) and 2-methoxyethanol (2ME) were mixed in a molar ratio of $(\text{TiP})/(\text{2ME}) = 0.0736$, while the ratio of $(\text{2ME})/(\text{EAA})$ was maintained at 13.2548. The mixture was magnetically stirred for 1 h to obtain a homogeneous TiO₂ sol. Subsequently, a surfactant was added under continuous stirring for 1 h. The prepared sol was used for the deposition of TiO₂ on a previously SiO₂ coated glass substrate using a sol-gel dip-coating unit named this samples as A-T. Using a similar procedure, Ag-doped TiO₂ samples were prepared with different at. % of Ag loading. The 0.5 at. % Ag-TiO₂ is prepared by adding required ratio of AgNO₃ precursor to prepared TiO₂ sol and labelled as B-T. Similarly, samples with different dopant concentrations of 1 at.% (C-T), 1.5 at.% (D-T), and 2 at.% (E-T) were prepared and labelled.

Catalysts characterization

To identify the crystal phase, X-ray diffraction (XRD) patterns were recorded using a Miniflex 600 RIKAGU X-ray diffractometer. The device was set to an $\alpha 1$ configuration and employed Cu K $\alpha 1$ radiation (1.5406 Å) for the XRD measurements. Measurements were taken over a broad angular range (2θ) from 20° to 80° in increments of 0.1°. Scherrer's equation was employed to calculate the average crystallite size, utilizing the broadening observed in the (101) reflection peak of the anatase. A Shimadzu UV-Vis spectrophotometer was used to measure the UV-Vis transmittance spectra of the TiO₂ coatings and dye concentration. An Agilent Cary 630 FTIR spectrophotometer was used to examine the bonding.

Photocatalytic cell configuration and examination

The photocatalytic performance of TiO₂ and Ag-TiO₂ films with varying atomic percentages of Ag doping was examined by monitoring the breakdown of the azo dye Plasmocorinth B (PB) in a water-based solution. The process was monitored using a Shimadzu UV-Vis spectrophotometer, which identified a distinctive absorption peak at 526 nm (λ_{max}). The dye solution was prepared in distilled water. Plasmocorinth B is an ideal model pollutant for photocatalytic evaluation because of its high aqueous solubility and molar absorptivity, which enables the precise detection of minor concentration changes. Its chemical stability in the absence of light ensures that any observed degradation is attributable solely to the photocatalytic process, providing a reliable benchmark for the catalytic efficiency [23]. For the experiment, a batch-type continuous-flow reactor with an online UV-Vis monitoring system was used. The prepared samples were placed inside a photocatalytic cell containing 12 ml of dye solution with an initial concentration of 10 mg L⁻¹.

Result and Discussion

XRD analysis

The X-ray diffraction (XRD) patterns of the TiO_2 and Ag- TiO_2 thin film deposited on SiO_2 precoated substrates are shown in Fig 1. The diffraction profiles revealed well-defined peaks, confirming the successful formation of a crystalline structure through the sol-gel synthesis route. The prominent diffraction peaks observed at 2θ values of 25.39° , 38° , 48.1° , and 54.32° are attributed to the (101), (004), (200), and (105) crystallographic planes of anatase TiO_2 respectively [24]. The peak at (101) shows the highest intensity, indicating its prominent orientation and significant contribution to the crystal structure. Additionally, doping of silver (Ag) in the TiO_2 lattice did not show any separate additional peak in the XRD patterns owing to the very low concentration and large dispersion of Ag into the TiO_2 matrix. In addition, the presence of Ag affects the microstructure and photocatalytic properties, as silver acts as an electron trapper, thereby reducing electron-hole recombination. The Scherrer equation was used to determine the average crystalline size of the TiO_2 and Ag- TiO_2 nanoparticles using the full width at half maximum (FWHM) of the most intense (101) diffraction peak. The calculated crystalline size for TiO_2 and Ag- TiO_2 is found to be 10.49 nm and 10.41 nm, respectively. Hence, the XRD analysis confirmed the formation of nanocrystalline TiO_2 with a pure anatase phase.

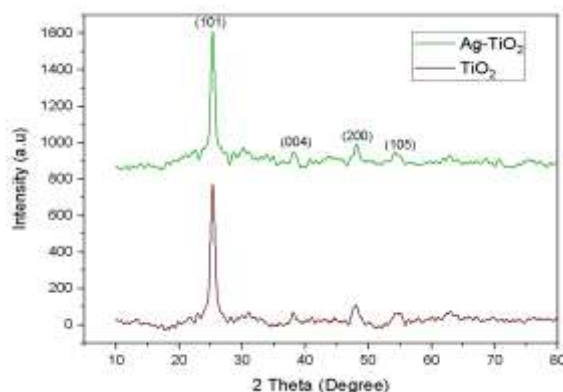


Fig 1: XRD spectrum of pure TiO_2 and Ag- TiO_2

UV- Visible analysis

The optical behavior of Ag-doped TiO_2 thin films was studied using UV-Vis spectroscopy. Fig. 2 shows reduction in band gap energy and red shift in absorption due to incorporation of Ag in TiO_2 lattice. This redshift indicates the successful doping of Ag into the TiO_2 matrix. This improvement in absorption comes from the formation of localized energy levels and the surface plasmon resonance effect [25]. The films show strong absorption in the UV region and high transiency in the visible region. With different doping percentages of Ag, 0.5 at% Ag- TiO_2 (B-T) shows a distinct redshift in the absorbance spectrum. This red shift in absorption suggests that doping of Ag in TiO_2 modifies electronic structure, narrows the band gap, or induces a localized surface plasmon resonance effect. Ag- TiO_2 (B-T) absorbs light at longer wavelengths, thereby enhancing its photocatalytic performance by expanding its activity in the visible region.

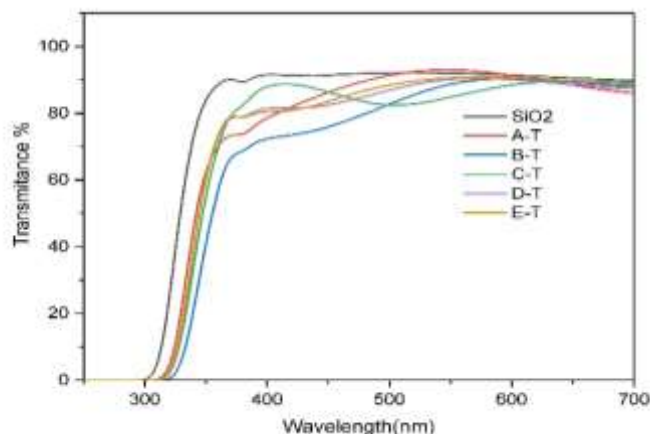


Fig 2: UV spectra of pure TiO_2 and Ag- TiO_2

FTIR Analysis

Fourier Transform IR spectroscopy used to analysed the chemical structures of the synthesized TiO_2 and Ag- TiO_2 , as illustrated in Fig.3. The FTIR results confirmed the formation of TiO_2 and displayed characteristic absorption peaks corresponding to TiO_2 . The spectrum shows well-defined peaks at 751.1 , 896.4 , 1047 , 1640 and 3373.2 , cm^{-1} . A broad peak in the 1000 – 400 cm^{-1} region corresponds to the Ti-O stretching and Ti-O-Ti bridging vibration modes [26]. In the 400 – 800 cm^{-1} range, the peak observed at 751.1 cm^{-1} for pure TiO_2 is linked to the anatase phase of titania. The stretching vibrations of Ti-O-Ti bonds are confirmed by the absorption band at 896.4 cm^{-1} in the IR spectrum [27, 28]. Additionally, the peak at 1047 cm^{-1} is ascribed to the C-O stretching vibration [29]. The bending vibration of the O-H bonds was observed at an absorption peak of 1627.28

cm^{-1} . The two broad peaks observed at 3373.2 and 1627.28 cm^{-1} are characteristic of surface-adsorbed water and hydroxyl groups, respectively [30]. Surface hydroxyl groups were found to be significantly present in TiO_2 . Furthermore, the small size of the crystallites may have caused peak broadening. The symmetric and asymmetric stretching vibrations of the Ti-OH bonds are associated with the spectroscopic band at approximately 3373.2 cm^{-1} [31]. Although there was no indication of Ag-O bond formation, FTIR analysis showed that the addition of silver changed the absorption band shape and intensity [32].

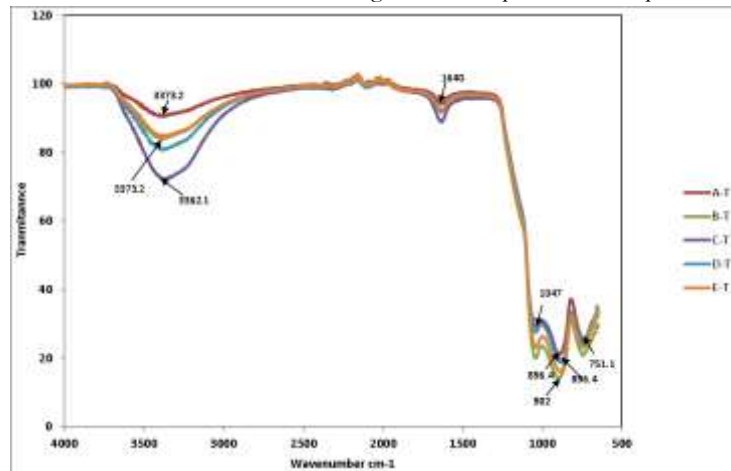


Fig 3: FTIR spectra of pure TiO_2 and Ag-TiO_2

Photocatalytic activity

The degradation performance of the prepared films is shown in Fig.4. An online measurement system was used to analyse the photocatalytic activity of the prepared TiO_2 and Ag-TiO_2 thin films. The performance was evaluated by monitoring the degradation of the azo dye, Plasmocorinth B (PB), under UV irradiation (UV lamp, 125 watt). Fig. 4 shows the plot of percentage removal efficiency with irradiation time; graph reveals that progress in exposure time is function of dye degradation. Furthermore, the Ag doping concentration (at.%) plotted against the rate constant (k) evidently reveals that the amount of Ag doping in the TiO_2 lattice strongly influenced the photocatalytic performance. The graph shows that the photocatalytic efficiency of TiO_2 considerably improved with Ag doping, with a maximum at 1at% Ag. This improvement results from Ag acting as an electron trapper, as it reduces electron-hole recombination. This charge undergoes a redox reaction, promoting the formation of reactive species, such as hydroxyl radicals ($\cdot\text{OH}$) and superoxide radicals ($\text{O}_2^{\cdot-}$), which are essential for the breakdown of dye molecules. Under UV light exposure, the Ag-TiO_2 photocatalyst with 1 at.% of Ag showed the highest activity, with nearly 70% degradation of Plasmocorinth B within 60 min, with a reaction rate of 0.09 min^{-1} . This signifies that the doping of Ag in the TiO_2 lattice improved the photocatalytic performance compared to pure TiO_2 . Beyond the optimum value, Ag doping decreases the photocatalytic efficiency. The accumulation of excess Ag nanoparticles on the TiO_2 surface blocked the active sites and decreased the light absorption efficiency, thereby reducing the efficiency. These findings show that optimizing the Ag concentration improves the photocatalytic performance of TiO_2 thin films by ensuring an effective equilibrium between enhanced charge separation and the surface activity of the photocatalyst.

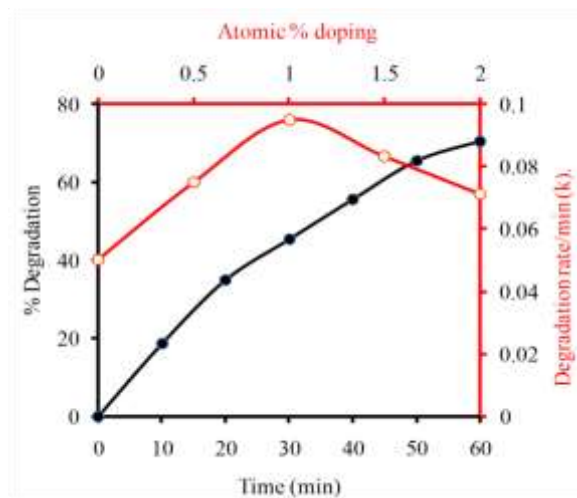


Fig 4: photocatalytic performance of pure TiO_2 and Ag-TiO_2

Mechanism of photocatalytic performance

A possible mechanism for the photocatalytic performance of Ag-TiO_2 thin films is visually demonstrated in Fig.5. Upon UV irradiation, the photogenerated electrons were absorbed by the Ag-TiO_2 photocatalyst. These photogenerated electrons excited from the valence to the conduction band leave holes behind in the valence band, generating electron-hole (e^-/h^+) pairs. The

photogenerated electrons react with dissolved oxygen, resulting in the formation of superoxide radicals ($O_2^{\cdot-}$), whereas holes interact with water or hydroxyl ions to produce hydroxyl radicals ($\cdot OH$) [19]. These reactive species play an important role for the degradation of the Plasmocorinth B azo dye. Pure TiO_2 suffers from the rapid recombination of electron-hole pairs, which affects the photocatalytic efficiency; however, the doping of Ag in TiO_2 significantly mitigates this recombination. Ag and TiO_2 have different Fermi levels, which causes an internal electric field to form at their interface and improves charge separation. Ag also enhances the optical characteristics by lowering the bandgap, which results in improved light absorption and a greater photo-response [33]. Plasmocorinth B degraded more quickly because of the increased availability of charge carriers to produce reactive radicals. Therefore, Ag- TiO_2 thin films perform better photocatalytically than pure TiO_2 because of improved charge separation, decreased recombination, and higher reactive species production.

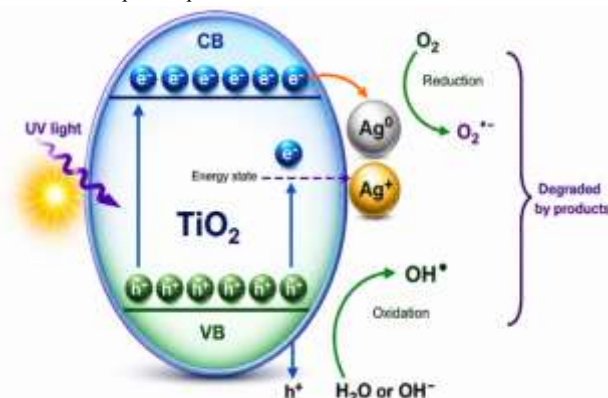


Fig 5: Mechanism of photocatalytic performance of Ag- TiO_2

Conclusion

The present study explored the potential of Ag- TiO_2 thin films for the photocatalytic degradation of azo dye. Pure TiO_2 and Ag- TiO_2 thin films were synthesized via the sol-gel dip-coating method. These thin films were characterized using X-ray diffraction (XRD), UV-visible spectroscopy, and Fourier-transform infrared (FTIR) spectroscopy. XRD revealed the formation of the anatase phase of TiO_2 with an average crystalline size of approximately 10.49 nm. Owing to the very low concentration of silver along with the uniform dispersion of Ag in the TiO_2 matrix, no distinct peak was observed for Ag in the XRD spectrum. A red shift in the transmission spectra was observed by UV-visible analysis, suggesting better light absorption in the visible region. The formation of the TiO_2 network was confirmed by FTIR analysis. Photocatalytic testing revealed that Ag- TiO_2 performed better than pure TiO_2 , degrading the Plasmocorinth B azo dye by approximately 70% in just 60 min. The sample containing 1 at% Ag exhibited the highest activity with a rate constant of 0.09 min⁻¹. According to our results, Ag- TiO_2 thin films are effective and promising photocatalysts for environmental remediation and dye degradation applications.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper

References:

1. Ajmal, A., Majeed, I., Malik, R. N., Idriss, H., & Nadeem, M. A. (2014). Principles and mechanisms of photocatalytic dye degradation on TiO_2 based photocatalysts: a comparative overview. *RSC Advances*, 4(70), 37003-37026. <https://doi.org/10.1039/C4RA06658H>
2. Huang, C. P., Dong, C., & Tang, Z. (1993). Advanced chemical oxidation: its present role and potential future in hazardous waste treatment. *Waste management*, 13(5-7), 361-377. [https://doi.org/10.1016/0956-053X\(93\)90070-D](https://doi.org/10.1016/0956-053X(93)90070-D)
3. Deng, Y., & Zhao, R. (2015). Advanced oxidation processes (AOPs) in wastewater treatment. *Current Pollution Reports*, 1, 167-176. <https://doi.org/10.1007/s40726-015-0015-z>
4. Mills, A., & Le Hunte, S. (1997). An overview of semiconductor photocatalysis. *Journal of photochemistry and photobiology A: Chemistry*, 108(1), 1-35. [https://doi.org/10.1016/S1010-6030\(97\)00118-4](https://doi.org/10.1016/S1010-6030(97)00118-4)
5. Akpan, U. G., & Hameed, B. H. (2009). Parameters affecting the photocatalytic degradation of dyes using TiO_2 -based photocatalysts: a review. *Journal of hazardous materials*, 170(2-3), 520-529. <https://doi.org/10.1016/j.jhazmat.2009.05.039>
6. Ali, M. M., Haque, M. J., Kabir, M. H., Kaiyum, M. A., & Rahman, M. S. (2021). Nano synthesis of ZnO- TiO_2 composites by sol-gel method and evaluation of their antibacterial, optical, and photocatalytic activities. *Results in Materials*, 11, 100199. <https://doi.org/10.1016/j.rinma.2021.100199>

7. Peiris, S., de Silva, H. B., Ranasinghe, K. N., Bandara, S. V., & Perera, I. R. (2021). Recent development and future prospects of TiO₂ photocatalysis. *Journal of the Chinese Chemical Society*, 68(5), 738-769. <https://doi.org/10.1002/jccs.202000509>
8. Padmanabhan, N. T., Thomas, N., Louis, J., Mathew, D. T., Ganguly, P., John, H., & Pillai, S. C. (2021). Graphene coupled TiO₂ photocatalysts for environmental applications: A review. *Chemosphere*, 271, 129506 <https://doi.org/10.1016/j.chemosphere.2020.129506>
9. Kanakaraju, D., A. Kutiang, F. D., Lim, Y. C., & Goh, P. S. (2022). Recent progress of Ag/TiO₂ photocatalyst for wastewater treatment: Doping, co-doping, and green materials functionalization. *Applied Materials Today*, 27, 101500. <https://doi.org/10.1016/j.apmt.2022.101500>
10. Chen, J., & Poon, C. S. (2009). Photocatalytic construction and building materials: from fundamentals to applications. *Building and environment*, 44(9), 1899-1906. <https://doi.org/10.1016/j.buildenv.2009.01.002>
11. Kumar, A., & Pandey, G. (2018). Different methods used for the synthesis of TiO₂ based nanomaterials: a review. *Am. J. Nano Res. Appl*, 6(1), 1. <https://doi.org/10.11648/j.nano.20180601.11>
12. Černigoj, U., Štangar, U. L., Trebše, P., Krašovec, U. O., & Gross, S. (2006). Photocatalytically active TiO₂ thin films produced by surfactant-assisted sol-gel processing. *Thin Solid Films*, 495(1-2), 327-332 <http://dx.doi.org/10.1016/j.tsf.2005.08.240>
13. Sonawane, R. S., Hegde, S. G., & Dongare, M. K. (2003). Preparation of titanium (IV) oxide thin film photocatalyst by sol-gel dips coating. *Materials chemistry and physics*, 77(3), 744-750. [https://doi.org/10.1016/S0254-0584\(02\)00138-4](https://doi.org/10.1016/S0254-0584(02)00138-4)
14. Pedrini, L. F., Escalante, L. C., & Scalvi, L. V. (2021). Deposition of TiO₂ thin films by dip-coating technique from a two-phase solution method and application to photocatalysis. *Materials Research*, 24(Suppl 1), e20210007. <https://doi.org/10.1590/1980-5373-MR-2021-0007>
15. Gogoi, D., Namdeo, A., Golder, A. K., & Peela, N. R. (2020). Ag-doped TiO₂ photocatalysts with effective charge transfer for highly efficient hydrogen production through water splitting. *International Journal of Hydrogen Energy*, 45(4), 2729-2744. <https://doi.org/10.1016/j.ijhydene.2019.11.127>
16. Lee, J. Y., & Choi, J. H. (2019). Sonochemical synthesis of Ce-doped TiO₂ nanostructure: a visible-light-driven photocatalyst for degradation of toluene and O-xylene. *Materials*, 12(8), 265. <https://doi.org/10.3390/ma12081265>
17. Mohammed, M. K. (2020). Sol-gel synthesis of Au-doped TiO₂ supported SWCNT nanohybrid with visible-light-driven photocatalytic for high degradation performance toward methylene blue dye. *Optik*, 223, 165607. <https://doi.org/10.1016/j.jleo.2020.165607>
18. Pérez-González, M., Tomás, S. A., Santoyo-Salazar, J., Gallardo-Hernández, S., Tellez-Cruz, M. M., & Solorza-Feria, O. (2019). Sol-gel synthesis of Ag-loaded TiO₂-ZnO thin films with enhanced photocatalytic activity. *Journal of Alloys and Compounds*, 779, 908-917. <https://doi.org/10.1016/j.jallcom.2018.11.302>
19. Pérez, J. B., Morales, E. R., Delgado, F. P., Avendaño, C. M., Guzman, E. A., & Mathews, N. R. (2023). Ag nanoparticle dispersed TiO₂ thin films by single step sol gel process: Evaluation of the physical properties and photocatalytic degradation. *Vacuum*, 215, 112276. <http://dx.doi.org/10.2139/ssrn.4391435>
20. Ogorevc, J. Š, Pirc, E. T., Matoh, L., & Bukovec, P. (2012). Antibacterial and Photodegradative Properties of Metal Doped TiO₂ thin Films under Visible Light. *Acta Chimica Slovenica*, 59(2). <https://doi.org/10.17344/acsi.2012.59.2.324>
21. N. Negishi, T. Iyoda, K. Hashimoto, A. Fujishima, Preparation of transparent TiO₂ thin film photocatalyst and its photocatalytic activity, *Chem. Lett.* (1995) 841-842. <https://doi.org/10.1246/cl.1995.841>
22. S.R. Patil, U.L. Stangar, S. Gross, U. Schubert, Super-hydrophilic and photocatalytic properties of Ag-TiO₂ thin film prepared by sol-gel technique, *J. Adv. Oxid. Technol.* 11 (2) (2008) 327-337. <https://doi.org/10.1515/jaots-2008-0211>
23. Varga, M., Takáts, V., & Kónya, Z. (2012). Antibacterial and photodegradative properties of metal-doped TiO₂ thin films under visible light. *Acta Chimica Slovenica*, 59(3), 466-472.
24. Muniandy, S. S., Kaus, N. H. M., Jiang, Z. T., Altarawneh, M., & Lee, H. L. (2017). Green synthesis of mesoporous anatase TiO₂ nanoparticles and their photocatalytic activities. *RSC advances*, 7(76), 48083-48094. <https://doi.org/10.1039/C7RA08187A>
25. Ali, T., Ahmed, A., Alam, U., Uddin, I., Tripathi, P., & Muneer, M. (2018). Enhanced photocatalytic and antibacterial activities of Ag-doped TiO₂ nanoparticles under visible light. *Materials Chemistry and Physics*, 212, 325-335. <https://doi.org/10.1016/j.matchemphys.2018.03.052>
26. Lu, H., Zhou, Y., Vongehr, S., Tang, S., & Meng, X. (2012). Effects of hydrothermal temperature on formation and decoloration characteristics of anatase TiO₂ nanoparticles. *Science China Technological Sciences*, 55(4), 894-902. <https://doi.org/10.1007/s11431-011-4706-4>
27. Lu, X., Lv, X., Sun, Z., & Zheng, Y. (2008). Nanocomposites of poly (L-lactide) and surface-grafted TiO₂ nanoparticles: Synthesis and characterization. *European Polymer Journal*, 44(8), 2476-2481. <https://doi.org/10.1016/j.eurpolymj.2008.06.002>
28. Xiao, J., Peng, T., Li, R., Peng, Z., & Yan, C. (2006). Preparation, phase transformation and photocatalytic activities of cerium-doped mesoporous titania nanoparticles. *Journal of Solid State Chemistry*, 179(4), 1161-1170. <https://doi.org/10.1016/j.jssc.2006.01.008>

29. Praveen, P., Viruthagiri, G., Mugundan, S., & Shanmugam, N. (2014). Structural, optical and morphological analyses of pristine titanium di-oxide nanoparticles–Synthesized via sol-gel route. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 117, 622–629. <https://doi.org/10.1016/j.saa.2013.09.037>
30. Demirci, S., Dikici, T., Yurddaskal, M., Gultekin, S., Toparli, M., & Celik, E. (2016). Synthesis and characterization of Ag doped TiO₂ heterojunction films and their photocatalytic performances. *Applied Surface Science*, 390, 591–601. <https://doi.org/10.1016/j.apsusc.2016.08.145>
31. Wei, J., Zhao, L., Peng, S., Shi, J., Liu, Z., & Wen, W. (2008). Wettability of urea-doped TiO₂ nanoparticles and their high electrorheological effects. *Journal of sol-gel science and technology*, 47(3), 311–315. <https://doi.org/10.1007/s10971-008-1787-z>
32. Saravanan, S., & Dubey, R. S. (2021). Optical performance of visible and near-infrared responsive TiO₂/Ag doped-SiO₂/TiO₂ thin films prepared by sol-gel spin-coating method. *Journal of Optoelectronics and Advanced Materials*, 23(9–10), 484–487.
33. Liza, T. Z., Tusher, M. M. H., Anwar, F., Monika, M. F., Amin, K. F., & Asrafuzzaman, F. N. U. (2024). *Effect of Ag-doping on morphology, structure, band gap and photocatalytic activity of bio-mediated TiO₂ nanoparticles*. *Results in Materials*, 22, 100559. <https://doi.org/10.1016/j.rinma.2024.100559>