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Processes of Synthesis and Characterization of Al and Cu Dopped Titanium Dioxide Nano Particle

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ABSTRACT: This review aims to provide a comprehensive overview of the synthesis processes and characterization techniques for Al and Cu doped TiO_2 nanoparticles. By analyzing the current state of research, we aim to highlight the advancements, challenges, and future prospects in this field. The synthesis methods are discussed in detail to understand the advantages and limitations of each approach, while the characterization results are presented to demonstrate the impact of doping on the properties and performance of TiO_2 nanoparticles. Through this review, we seek to elucidate the potential of Al and Cu doped TiO_2 nanoparticles in enhancing photocatalytic activities and contributing to the development of advanced materials for environmental and energy applications.

KEYWORDS: Nano Particle, Al and Cu doped TiO_2, Synthesis Methods.

I.INTRODUCTION

Titanium dioxide (TiO_2) nanoparticles have garnered significant attention due to their versatile applications in photocatalysis, environmental remediation, solar cells, and sensors. Their remarkable photocatalytic properties, chemical stability, non-toxicity, and cost-effectiveness make TiO_2 an ideal material for various technological advancements. However, pure TiO_2 has limitations, such as a relatively large bandgap (3.2 eV for the anatase phase), which restricts its photocatalytic activity to the ultraviolet (UV) region of the light spectrum, accounting for only about 5% of the solar spectrum.

To enhance the photocatalytic efficiency and extend the light absorption range of TiO_2 into the visible region, doping with metal ions has emerged as an effective strategy. Among the various dopants explored, aluminum (Al) and copper (Cu) have shown promising results. Al doping is known to enhance the thermal stability and crystallinity of TiO_2, while Cu doping introduces additional energy levels within the bandgap, facilitating better utilization of visible light.

This review focuses on the synthesis and characterization of Al and Cu doped TiO_2 nanoparticles. The incorporation of these dopants into the TiO_2 lattice modifies the electronic structure, leading to improved charge separation and reduced recombination of electron-hole pairs, thereby enhancing photocatalytic performance. Various chemical synthesis methods, including sol-gel, co-precipitation, and hydrothermal techniques, have been employed to achieve uniform doping and control over nanoparticle size and distribution.

Characterization techniques such as X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), energy-dispersive X-ray spectroscopy (EDX), X-ray photoelectron spectroscopy (XPS), UV-Vis spectroscopy, and photoluminescence (PL) spectroscopy are crucial for understanding the structural, morphological, chemical, and optical properties of the doped TiO_2 nanoparticles. These techniques provide insights into the crystallite size, phase composition, surface morphology, elemental composition, chemical states, bandgap energy, and electron-hole recombination rates.

II. SYNTHESIS METHODS

Titanium dioxide (TiO_2) nanoparticles are widely recognized for their exceptional photocatalytic properties, making them suitable for applications in environmental remediation, solar energy conversion, and antibacterial treatments.

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However, the relatively large bandgap of pure TiO_2 limits its photocatalytic activity to the UV region, necessitating the development of modified TiO_2 with enhanced visible light absorption.

Doping TiO_2 with metal ions such as aluminum (Al) and copper (Cu) has proven effective in narrowing the bandgap and improving charge carrier dynamics. This review focuses on the chemical synthesis methods for Al and Cu doped TiO_2 nanoparticles and the characterization techniques used to evaluate their properties.

Sol-Gel Method

The sol-gel method is a versatile chemical technique used for synthesizing Al and Cu doped TiO_2 nanoparticles, offering precise control over particle size and dopant distribution. This method involves hydrolyzing titanium alkoxide precursors in the presence of aluminum and copper salts, forming a homogeneous sol. The sol undergoes gelation, drying, and calcination to produce crystalline doped TiO_2 nanoparticles. The sol-gel process is favored for its ability to produce uniform, high-purity nanoparticles with enhanced photocatalytic properties, making it ideal for applications in environmental remediation, solar energy, and other advanced materials technologies.
Procedure:

1. Precursor Preparation:
   - Titanium isopropoxide ($Ti[OCH(CH_3)_2]_4$) is used as the titanium source.
   - Aluminum nitrate ($Al(NO_3)_3$) and copper nitrate ($Cu(NO_3)_2$) serve as dopant sources.
2. Hydrolysis and Gelation:
   - The precursors are dissolved in ethanol and hydrolyzed by adding water with constant stirring, forming a sol.
   - The sol undergoes gelation, forming a gel-like substance.
3. Drying and Calcination:
   - The gel is dried to remove solvents and then calcined at high temperatures (400-600°C) to crystallize the TiO_2 nanoparticles and incorporate the dopants.

Advantages:

- Produces uniform nanoparticles with controlled size and composition.
- Allows precise control over doping levels.

Co-Precipitation Method

The co-precipitation method is an efficient chemical synthesis technique for producing Al and Cu doped TiO_2 nanoparticles. This method involves dissolving titanium, aluminum, and copper precursors in an aqueous solution, followed by the addition of a base to precipitate TiO_2 along with the dopants. The resulting precipitate is then washed, filtered, dried, and calcined to achieve the desired crystalline structure. Co-precipitation is advantageous for its simplicity, cost-effectiveness, and ability to achieve homogeneous doping, making it a popular choice for enhancing the photocatalytic properties of TiO_2 nanoparticles for various environmental and energy applications.
Procedure:

1. Precursor Solution:
   - Titanium chloride ($TiCl_4$) or titanium sulfate ($Ti(SO_4)_2$) is dissolved in water along with aluminum and copper salts.

2. Precipitation:
   - A base, such as ammonium hydroxide (NH_4OH), is added to the precursor solution, causing TiO_2 and the dopants to precipitate out of solution.
3. Washing and Calcination:
   - The precipitate is washed, filtered, and dried.
   - The dried product is then calcined to achieve the final doped TiO_2 nanoparticles.

Advantages:
- Simple and cost-effective.
- Effective for achieving homogeneous doping.

Hydrothermal Method

The hydrothermal method is a robust chemical synthesis technique used to produce Al and Cu doped TiO_2 nanoparticles. This method involves dissolving titanium, aluminum, and copper precursors in an aqueous solution, which is then sealed in an autoclave and heated to high temperatures under pressure. This process promotes crystal growth and uniform doping. The resulting product is washed and dried to obtain doped TiO_2 nanoparticles with high crystallinity and controlled morphology. The hydrothermal method is favored for its ability to produce high-quality nanoparticles with enhanced photocatalytic properties, making it suitable for applications in environmental remediation and solar energy conversion.
Procedure:

1. Solution Preparation:
   - Titanium precursor, aluminum, and copper salts are dissolved in an aqueous solution.
2. Hydrothermal Treatment:
   - The solution is transferred to a sealed autoclave and heated to high temperatures (100-200°C) under pressure for several hours.
3. Post-Treatment:
   - The resulting product is washed and dried to obtain doped TiO_2 nanoparticles.

Advantages:
- Produces nanoparticles with high crystallinity.
- Good control over particle size and morphology.

III. CHARACTERIZATION TECHNIQUES

Characterization techniques are essential for understanding the properties and performance of Al and Cu doped TiO_2 nanoparticles. These methods provide detailed insights into the structural, morphological, chemical, and optical attributes of the synthesized nanoparticles. Techniques such as X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), energy dispersive X-ray spectroscopy (EDX), X-ray photoelectron spectroscopy (XPS), UV-Vis spectroscopy, and photoluminescence (PL) spectroscopy are commonly employed. These analyses confirm successful doping, determine particle size and distribution, assess chemical states, and evaluate improvements in photocatalytic activity, guiding the development of advanced materials for environmental and energy applications.

1. **X-Ray Diffraction (XRD):**
   - Determines crystal structure, phase composition, and crystallite size.
   - Successful doping is indicated by shifts in peak positions and changes in peak intensities.

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2. **Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM):**
    - SEM: Examines surface morphology and particle size.
    - TEM: Provides detailed insights into internal structure and confirms uniform doping.
3. **Energy Dispersive X-Ray Spectroscopy (EDX):**
    - Confirms elemental composition and distribution of Al and Cu within the TiO_2 matrix.
4. **X-Ray Photoelectron Spectroscopy (XPS):**
    - Analyzes chemical states of Ti, Al, and Cu, confirming their incorporation into the TiO_2 lattice.
5. **UV-Vis Spectroscopy:**
    - Assesses optical properties and bandgap energy.
    - Doping usually results in a red shift, indicating bandgap narrowing.
6. **Photoluminescence (PL) Spectroscopy:**
    - Studies the recombination rate of electron-hole pairs.
    - Reduced PL intensity suggests enhanced charge separation efficiency.

V. RESULTS AND DISCUSSION

The results of various studies on the chemical synthesis of Al and Cu doped TiO_2 nanoparticles typically indicate:

- XRD: Retention of anatase phase with slight shifts in peak positions due to doping. Calculations using the Scherrer equation reveal crystallite size.
- SEM and TEM: Well-dispersed nanoparticles with uniform size, showing that doping does not significantly alter morphology.
- EDX and XPS: Confirmation of successful doping and appropriate chemical states (Al^{3+} and Cu^{2+}).
- UV-Vis and PL: Red shift in absorption edge (bandgap narrowing) and reduced PL intensity, indicating better light absorption and charge separation.

VI. CONCLUSION

Chemical synthesis methods, particularly the sol-gel, co-precipitation, and hydrothermal methods, are effective in producing Al and Cu doped TiO_2 nanoparticles with enhanced photocatalytic properties. These methods allow precise control over particle size, morphology, and doping levels, resulting in nanoparticles with improved visible light absorption and charge carrier dynamics. Characterization techniques confirm the successful incorporation of dopants and the resulting improvements in properties. These advancements hold significant promise for applications in photocatalysis and other areas requiring efficient light-induced reactions.

REFERENCES

[1] Ganesh, I., Kumar, P.P., Annapoorna, I., Sumliner, J.M., Ramakrishna, M., Hebalkar, N.Y., Padmanabham, G. and Sundararajan, G., 2014. Preparation and characterization of Cu-doped TiO2 materials for electrochemical, photoelectrochemical, and photocatalytic applications. *Applied Surface Science*, *293*, pp.229-247.

[2] Yadav, H.M., Otari, S.V., Koli, V.B., Mali, S.S., Hong, C.K., Pawar, S.H. and Delekar, S.D., 2014. Preparation and characterization of copper-doped anatase TiO2 nanoparticles with visible light photocatalytic antibacterial activity. *Journal of Photochemistry and Photobiology A: Chemistry*, *280*, pp.32-38.

[3] Yang, X.J., Shu, W.A.N.G., Sun, H.M., Wang, X.B. and Lian, J.S., 2015. Preparation and photocatalytic performance of Cu-doped TiO2 nanoparticles. *Transactions of Nonferrous Metals Society of China*, *25*(2), pp.504-509.

[4] Peter Etape, E., John Ngolui, L., Foba-Tendo, J., Yufanyi, D.M. and Victorine Namondo, B., 2017. Synthesis and Characterization of CuO, TiO2, and CuO-TiO2 Mixed Oxide by a Modified Oxalate Route. *Journal of Applied Chemistry*, *2017*(1), p.4518654.

[5] Shi, J.W., Zheng, J.T. and Wu, P., 2009. Preparation, characterization and photocatalytic activities of holmium-doped titanium dioxide nanoparticles. *Journal of Hazardous Materials*, *161*(1), pp.416-422.

[6] Liu, G., Han, C., Pelaez, M., Zhu, D., Liao, S., Likodimos, V., Ioannidis, N., Kontos, A.G., Falaras, P., Dunlop, P.S. and Byrne, J.A., 2012. Synthesis, characterization and photocatalytic evaluation of visible light activated C-doped TiO2 nanoparticles. *Nanotechnology*, *23*(29), p.294003.

[7] Ahadi, S., Moalej, N.S. and Sheibani, S., 2019. Characteristics and photocatalytic behavior of Fe and Cu doped TiO2 prepared by combined sol-gel and mechanical alloying. *Solid State Sciences*, *96*, p.105975.

[8] Lin, K.S., Cheng, H.W., Chen, W.R. and Wu, J.F., 2010. SYNTHESIS, CHARACTERIZATION AND APPLICATION OF ANATASE-TYPED TITANIA NANOPARTICLES. *Journal of Environmental Engineering & Management*, *20*(2).

[9] Srivastava, S., Kumar, S., Singh, V.N., Singh, M. and Vijay, Y.K., 2011. Synthesis and characterization of TiO2 doped polyaniline composites for hydrogen gas sensing. *International Journal of Hydrogen Energy*, *36*(10), pp.6343-6355.

[10] Sohrabi, S. and Akhlaghian, F., 2016. Modeling and optimization of phenol degradation over copper-doped titanium dioxide photocatalyst using response surface methodology. *Process Safety and Environmental Protection*, *99*, pp.120-128.