

Green Sol-gel Synthesis of TiO₂, SiO₂, and ZnO Based Photocatalytic Coatings for Environmental Cleanup

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Abstract

Photocatalytic coatings have gained huge attention for environmental cleanup, especially in air and water purification. Current research is focused on developing an eco-friendly and sustainable synthesis approach for TiO₂, SiO₂, and ZnO based photocatalytic coatings using sol-gel and dip-coating technique. Distilled water, acetic acid, and oxide precursors only, were used in synthesis to avoid hazardous solvents and to ensure a green synthesis route. The influence of aging time, synthesis temperature and deposition conditions were systematically evaluated to optimize the coatings for improved photocatalytic performance. The TiO₂ sol was prepared at room temperature, 40°C, and 50°C to study the effects of temperature over its stability and photocatalytic efficiency; SiO₂ and ZnO sols were prepared at room temperature. The final sols were coated over 2.5×2.5 cm² glass substrate by single and multilayer dipping. Each coated layer was post-annealed at 400°C prior to further deposition. However, SiO₂ layers were dried at room temperature prior to deposit further layers. The stability of the sols over aging was evaluated by dynamic light scattering (DLS). The finally prepared coatings were characterized by x-ray diffraction (XRD), energy dispersive spectroscopy (EDS) and field emission scanning electron microscope (FE-SEM) for structural and morphological evaluation. The photocatalytic ability of coatings was tested by photodegradation of rhodamine B (RhB) dye under UV (λ = 365 nm) and visible light irradiance.

DLS study of TiO₂ sol revealed nanoparticles formation (10 - 100 nm) with increasing sizes over aging, indicating particles growth and colloidal instability. XRD confirmed the presence of pure anatase phased TiO₂ nanoparticles with major peak (101) at 25.30° and average crystallite size of 5 nm while formation of crystalline ZnO was confirmed by (100) phase with average crystallite size of 23 nm. EDS also confirmed the elemental composition of all coatings. FE-SEM revealed a crack-less and uniform morphology of SiO₂-TiO₂ coatings among all other coatings. The interlayer of SiO₂ improved TiO₂ dispersion and adhesion over glass substrate by reducing the interfacial stress.

The SiO₂-TiO₂ coatings showed 100% photocatalytic degradation of RhB under UV irradiance with kinetic constant of 0.0127 min⁻¹, while TiO₂ coatings showed 92% degradation with a rate constant of 0.0102 min⁻¹. The porous nature of SiO₂ enabled

better dispersion of TiO_2 with higher active surface area and prevented agglomeration and delamination during photocatalytic reactions which directly improved the photocatalysis efficiency of coatings. The heating effect also accelerated hydrolysis and resulted in production of larger number of crystallites in TiO_2 sol which improved its photocatalytic efficiency. ZnO showed 36% degradation with a rate constant of 0.0013 min^{-1} , $\text{SiO}_2\text{-ZnO}$ showed 49% with a rate constant of 0.0019 min^{-1} , and $\text{TiO}_2\text{-ZnO}$ showed 62% with a rate constant of 0.0037 min^{-1} . In visible driven photocatalysis only ZnO coating showed 56% degradation with a rate constant of 0.0025 min^{-1} , while other coatings do not show significant degradation.

Overall, this research contributes to the development of efficient photocatalytic coatings for environmental applications. Further optimization of sol formulations, deposition and testing conditions could improve the performance of these materials in real-world applications.