

Low-Temperature Aqueous Sol-Gel Synthesis of Ta-, V-, and Nb-Doped TiO₂ Photocatalysts for Superior Degradation of Refractory Pollutants under UV-Visible Light

Julien G. Mahy^{1*}, Maxine Mathy¹, Antoine Farcy¹, Sophie Hermans², Stéphanie D. Lambert¹,

¹ Department of Chemical Engineering – Nanomaterials, Catalysis & Electrochemistry, University of Liège, Liège, Belgium

² Institute of Condensed Matter and Nanosciences - Molecular Chemistry, Materials and Catalysis (IMCN/MOST), Université catholique de Louvain, Place Louis Pasteur 1, Box L4.01.03, 1348 Louvain-La-Neuve, Belgium

*Corresponding author: Julien Mahy; email: julien.mahy@uliege.be; address: Allée du Six Août 11, 4000 Liège, Belgium

Abstract

In the quest for efficient, sustainable water treatment solutions, advanced oxidation processes like photocatalysis offer immense promise for degrading refractory organic contaminants. This study introduces an innovative, low-temperature aqueous sol-gel method to synthesize crystalline TiO₂-based photocatalysts doped with tantalum (Ta), vanadium (V), or niobium (Nb) at varying molar ratios (0.1–16 mol%), eliminating the need for energy-intensive calcination steps. This eco-friendly approach yields high-surface-area materials (up to 292 m²/g) with biphasic anatase-brookite structures, as confirmed by XRD, TEM, and BET analyses. ICP-AES, EDX, and XPS verify dopant incorporation, revealing nitrogen co-doping in undoped TiO₂ and oxidation states like Ta⁵⁺, V⁵⁺, and Nb⁵⁺. UV-Vis diffuse reflectance spectroscopy demonstrates bandgap narrowing, particularly with V-doping (from 2.95 eV to 1.88 eV), enabling visible-light activation.

Photocatalytic screening on p-nitrophenol (PNP) degradation under UV-visible (300–800 nm) and visible light (395–800 nm) highlights dopant-dependent enhancements: Ta and Nb doping boost visible-light efficiency to 37% and 55% (vs. 22% for undoped TiO₂), while V-doping reduces it to 3–12%. Kinetic studies, scavenger experiments, and recycling tests (up to 120 h) confirm stability and radical-driven mechanisms. Pioneering electrophotocatalytic tests in a custom setup show Nb-doped TiO₂ coatings on Pt anodes achieving 94% PNP mineralization under UV (vs. 72% uncoated), underscoring synergistic electro-photo effects.

This sol-gel innovation advances TiO₂ photocatalysts beyond commercial benchmarks like Evonik P25, offering scalable, cost-effective materials for quaternary wastewater treatment and solar-driven purification.

Keywords: Sol-gel synthesis; TiO₂; Metal doping; Tantalum; Niobium; Vanadium; Photocatalysis; Electrophotocatalysis; Visible light; p-Nitrophenol