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Pioneering TiO_2/G-C_3N_4 Heterostructures for Enhanced Organic Pollutant Removal

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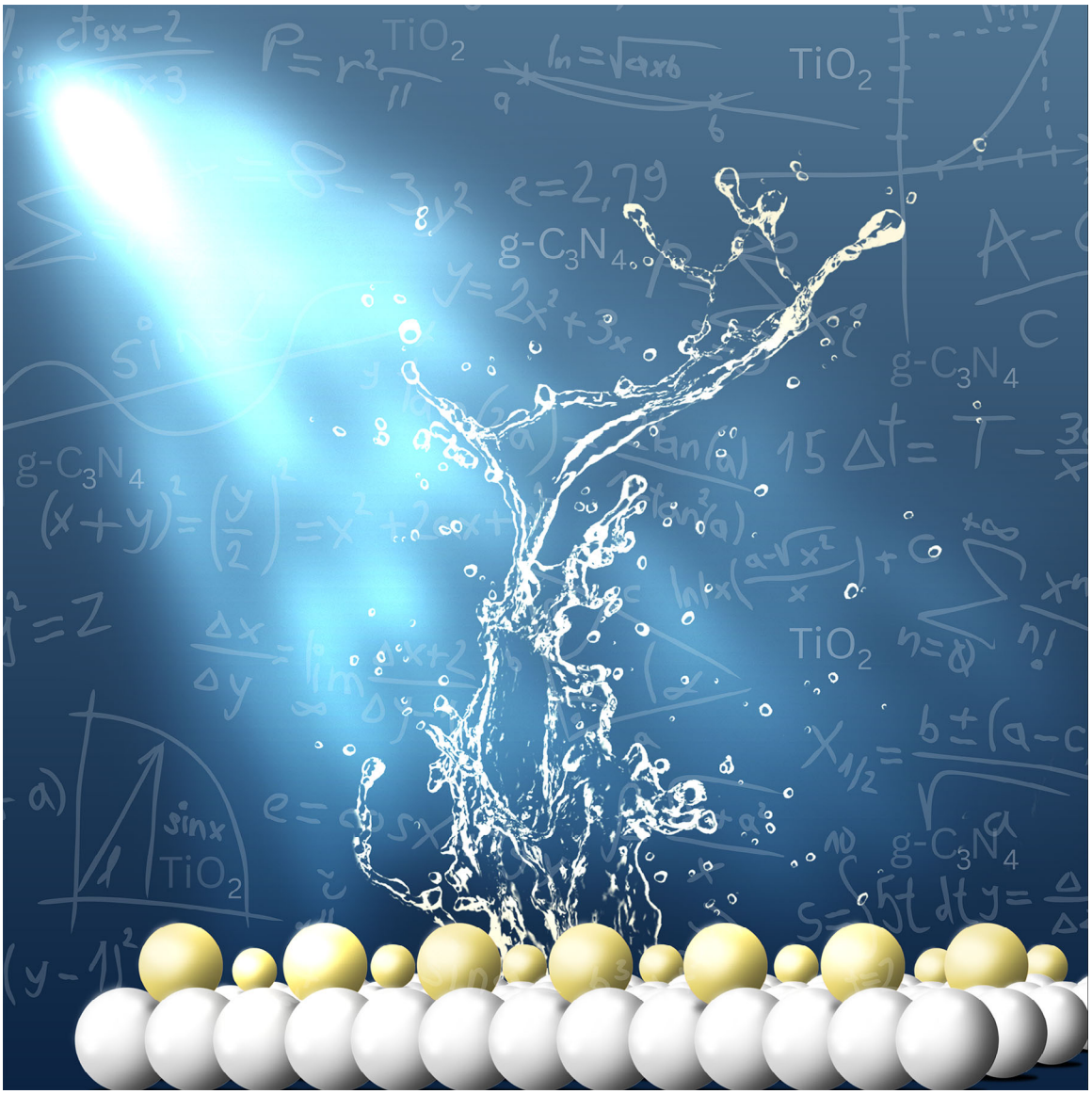

The remarkable synergy and versatility of TiO2/g-C3N4 composites in photocatalytic applications, particularly for the removal of organic pollutants, have attracted considerable interest. This review provides a comprehensive overview of the modifications employed to enhance the properties of binary TiO2/g-C3N4 heterostructures. The examination encompasses the modification of binary TiO2/g-C3N4 systems with various materials, including metal and nonmetal dopants, carbonaceous supports, and other semiconductors, among others. The effects of various parameters, such as synthesis methods, types of precursors, calcination procedures, and concentrations of precursors, are also correlated with the physicochemical properties and photocatalytic performance of the materials. This in-depth exploration highlights TiO2/g-C3N4 advancements in engineering, more advanced and smart materials with enhanced visible light utilization and charge-transfer ability. Additionally, the review highlights the need for further investigation into the underlying mechanisms involved and the advancement of synthesis techniques that are both scalable and environmentally sustainable. Future directions for improving TiO2/g-C3N4-based heterostructures are presented, with an emphasis on the potential to revolutionize photocatalysis for environmental remediation and sustainable energy generation.

1. Introduction

In recent times, the escalation of global environmental pollution and its potential repercussions on aquatic ecosystems and human health have become subjects of increasing apprehension. The sources of this pollution encompass newly identified pollutants and endocrine-disrupting chemicals, such as pharmaceuticals, fertilizers, phenolic compounds, and dyes, all of which stem from various anthropogenic activities. These substances arise from a broad spectrum of human activities, adding to the complexity of the issue. For example, pharmaceuticals are commonly detected in various sources of surface water and wastewater treatment influents and effluents due to their widespread usage in human and veterinary medicine, besides improper disposal.[1,2] Likewise, dyes, which are heavily applied in the textile, apparel and paper industries, can cause damage to living organisms.[3] Meanwhile, phenolic compounds released from various industrial activities (e.g., agriculture and pharmaceuticals) are known for their toxicity and carcinogenic, mutagenic, and teratogenic effects.[4]

Traditional wastewater treatment techniques, which can be classified into chemical, biological, and physical methods, have historically been employed to address the presence of these pollutants in wastewater. Nevertheless, these customary methods are not without drawbacks, such as the generation of significant amounts of sludge, the production of toxic byproducts, substantial costs, and a protracted processing time.

Some organic pollutants are resistant to conventional wastewater technologies, which decreases degradation performance. For the past few decades, advanced oxidation processes (AOPs) have emerged in the wastewater treatment field. These processes offer a solution to the constraints associated with conventional treatment methods.[5] AOPs revolve around the in situ generation of potent oxidation agents, with a particular emphasis on hydroxyl (•OH) radicals.[6] Many AOPs based on •OH radicals have been applied to reduce organic pollutants into simpler and nontoxic substances. The widespread application of •OH radicals is due to their nonselective nature and the presence of at least a single unpaired electron responsible for the pollutant oxidation process.[7] Photocatalysis is a green technique that has attracted vast attention for the mineralization of contaminants from water and their conversion into non-hazardous compounds. The International Union of Pure and Applied Chemistry (IUPAC) defined photocatalysis as a process that modifies the rate of a chemical reaction or initiates it when subjected to ultraviolet, visible, or infrared radiation. This occurs in the presence of a photocatalyst, a substance that absorbs light and participates in the chemical transformation of the reactants involved in the reaction.[8] In general, a good photocatalyst must exhibit high photocatalytic activity, slow electron-hole recombination, a high specific surface area, and good recovery and recyclability. Among the myriads of semiconductors available, titanium dioxide (TiO_2) is a promising candidate for photocatalysis, owing to its stability, affordability, and nontoxic nature. Despite these positive advantages, its fast electron-hole recombination rate and wide band gap (3.2 eV for anatase) limit its activation to the ultraviolet (UV) light region ($<$ 400 nm). TiO_2 can absorb only UV light, which constitutes less than 5% of the entire solar spectrum.[9] In addition, the spontaneous agglomeration of TiO_2 nanoparticles in a suspension presents another drawback, leading to a rapid reduction in the specific surface area of the material and, consequently, a rapid decrease in its photocatalytic efficacy. Collectively, these drawbacks have thwarted the widespread deployment of TiO_2 nanoparticles in large-scale applications.[10]

Graphitic carbon nitride (g-C_3N_4), a metal-free polymeric material, has piqued the curiosity of researchers since its initial use for visible-light-driven photocatalytic hydrogen (H_2) production in 2009.[11] The band gap of pristine g-C_3N_4 is ~2.7 eV, making it particularly adept at harnessing visible light illumination within the wavelength range of 450–470 nm.[12] g-C_3N_4

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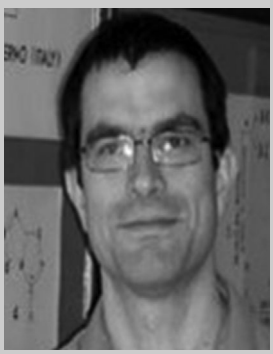
Danielson Ngo Joseph completed his bachelor's degree in esource chemistry at Universiti Malaysia Sarawak (UNIMAS) in 2023. Currently, he is pursuing a master of science in environmental chemistry. His current research is focused on the fabrication of Ag-TiO_2-based photocatalysts with perovskites and carbonaceous materials by utilizing waste.

Pheodora Pamela Natashya completed her bachelor's degree in resource chemistry at Universiti Malaysia Sarawak (UNIMAS) in 2022. At the end of 2022, she returned to UNIMAS to pursue a master's degree in environmental chemistry. Her current research is focused on advanced materials, particularly on the development of TiO_2-based ternary photocatalysts for the removal of organic pollutants from wastewater.



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Conflict of Interests

The authors declare no conflict of interest.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.