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Outlook on bismuth-based photocatalysts for environmental applications: A specific emphasis on Z-scheme mechanisms

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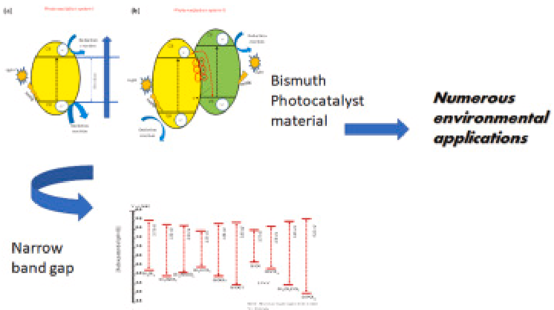
Abstract

Semiconductor photocatalysis is thought to be a viable solution for addressing the growing problem of environmental pollution. Bismuth (Bi) metal oxides can function as a direct plasmonic photocatalyst or cocatalyst to accelerate the photogenerated charge separation and thus improve their photocatalytic activity. Hence, Bi-based photocatalysts have received a lot of attention due to their extensive environmental applications, including pollutant remediation and energy concepts. Massive efforts have been undertaken in the recent decade to find superior Bi-metal oxides (Bi_2XO_6, X=MO, W, or Cr) and to uncover the corresponding photocatalytic reaction mechanism for the degradation of organic contaminants in water. Herein, the unique crystalline and electronic properties and main synthesis methods, as well as the major Bi-Based direct Z-scheme photocatalysts, are timely discussed and summarized in their usage in water treatment. Besides, the impact of Bi_2XO_6 in energy storage devices and solar energy conversion is reviewed as an energy application. Finally, the future development and challenges of Z-scheme-based Bi_2XO_6 photocatalysts are briefly explored, summarized, and forecasted.

Graphical abstract



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Introduction

A cleaner and sustainable environment is a major requirement in the present era as it deals with waste material reduction, removal, recycling, and clean energy generation. In the context of water pollution, the ubiquitous and persistent organic micropollutants in water bodies are developing hazards to human health (Chawla et al., 2021). The environment is being contaminated by various biological and chemical contaminants due to the reckless activities of a rapidly rising human population. The quality of our drinking water resources is deteriorating due to rising pollution. Organic contaminants, especially chemical contaminants, are on the rise as a result of industrial wastes, hospital and laboratory water wastes, and other sources, including domestic wastes (Kumar et al., 2021). Toxic contaminants in polluted water have major consequences for human health, the environment, and, as a result, the economy; this necessitates immediate attention to the development of wastewater treatment technology that may be reused, thereby lowering the environmental impact (Kallawar et al., 2021). Separation, precipitation, sedimentation, filtration, centrifugation, flocculation, and other traditional procedures have been utilised to purify the wastewater. However, these technologies have drawbacks, such as reduced removal efficiency, secondary pollution creation, and larger investments, limiting commercial uses (Arumugam et al., 2021). As a result, there is a need to design a wastewater treatment method that is both successful and inexpensive.

Due to the fast rise of the human population and economic progress in recent decades, human society has had an unquenchable and voracious thirst for fossil fuels. Continuous depletion of fossil fuels has resulted in a slew of global issues, including deteriorating environmental conditions and an energy crisis, two of humanity's most pressing issues today (Liu et al., 2022). Energy generation, storage, harvesting, and transportation are critical for maintaining the cost of living in developed and developing countries, as any country's progress is more or less reliant on resource availability. The need for energy will significantly expand in the next years, becoming 10-fold larger than it is now; as a result, there will be a need to obtain energy from current products and services. As a result, the need for high-performance, low-cost, and pollution-free or environmentally friendly energy generation systems is growing by the day (Shinde et al., 2019). Using zero-carbon or low-carbon energy to replace fossil fuels to achieve relatively zero emissions is currently one of the most promising approaches to minimise CO_2 emissions from industrial activity. Clean hydrogen produced from low- or zero-emission sources can help the energy and industrial sectors achieve deep decarbonization (Liu et al., 2022).

Photocatalysis is a sustainable process that involves transforming solar energy into chemical energy. It may be described as the acceleration of any chemical reaction by direct or catalytic irradiation of photons that decreases the activation energy for a reaction to occur. It is an advanced oxidation (AO) process in which photons participate both actively and passively in the generation of hydrogen by water splitting in the presence of light radiations. It is mostly used to treat waste water in order to safeguard the environment (Chawla et al., 2021). Semiconductor photocatalysis, in particular, has shown great promise in the fields of organic pollutant degradation, water splitting, CO_2 reduction to sustainable fuels, and so on (L. Guo et al., 2021). In recent years, the evolution of hydrogen from water via a photocatalytic or electrocatalytic process has received a lot of attention (Liu et al., 2022).

As a result, numerous researchers have produced photocatalyst materials that are active in visible, ultraviolet, visible, and near-infrared radiation under different light sources (Wang et al., 2022). In a huge family of semiconductors, Bi-based semiconductor photocatalysts have drawn a lot of attention in the photocatalyst world because of their unusual crystal structure, electrical configuration, and environmental friendliness. The photocatalytic performance of Bi-based semiconductors as photocatalysts, on the other hand, is limited by low photo-absorption and poor charge separation efficiency (Batool et al., 2021; Kallawar et al., 2021). The use of Z-scheme heterojunctions for solar energy conversion is important because it preserves the photocatalyst's strong reduction and oxidation capacities and high charge separation efficiency (L. Guo et al., 2021). Hence, this review focuses on the unique features and synthesis methods for Z-scheme-based Bi_2XO_6 (X=MO, W, or Cr) photocatalysts, as well as their environmental and energy applications, to give readers a wide overview and recent advancements.

Section snippets

Bibliometric analysis

Bibliometric analysis is a well-established and efficient method for identifying research issues and trends. It has been used in a variety of science and engineering fields. Scopus database is selected as a source to obtain the published documents because it is widely regarded as one of the most credible and accurate databases of interdisciplinary scientific evidence (Manikandan et al., 2021). A bibliometric analysis of global research output on a specific set of topics can track the evolution…

Crystallographic and electronic attributes of bismuth Z-schemes

A component's crystallographic and electronic attributes are intrinsically associated with its photocatalytic action'; likewise, the crystallographic and electronic attributes of Bi_2MoO_6 are matched. The $\alpha Bi_2Mo_3O_{12}$ form comprises a flawed scheelite arrangement; hence, for each of three Bi atoms, one is unoccupied; the $\beta Bi_2Mo_2O_9$ form also comprises a flawed arrangement of fluorite segment with metal position openings, while the γBi_2MoO_6 form is an archetypal Aurivillius-bismuth oxides group with …

Production techniques of Z-scheme photocatalysts

An extreme-competence Z-scheme photocatalytic scheme necessitates a fine bandgap for adequate photo-engagement and negative Conduction-Band (CB) and positive Valance-Band (VB) potentials for robust redox competencies, which are the inconsistent aspects and are very tough to attain in sole-module semiconductors. Moreover, the sole-module photocatalysts' rearrangement of photogeneration electrons and openings is also swift. Numerous exploration attempts have been performed over the years to…

Environmental applications of Bi-based photocatalysts

Bi compounds are generally thought to be non-toxic to living organisms. The non-toxic character of Bi and its derived compounds, as well as its insolubility in biological fluids, are important considerations that have led to their employment in a variety of medications for a variety of biological and chemical applications. Both geometries of compounds and the ligand utilised often depend on the natural activities of Bi-based drugs (Di et al., 2017; Dutta et al., 2020). Non-toxic pigment,…

Current status, prospects, and conclusion

Bismuth-centered photocatalysts have distinct features and attributes that encourage this as a unique resource for various environmental appliances. However, pure bismuth-centered photocatalysts have many intrinsic constraints such as a dearth of surface-active positions, inadequate light absorption extending bandgap, etc.; many approaches have been picked to improve photocatalytic action to meet the requirements of a potent agent. Various research points out that most demerits have been…

Credit author statement

Srinivasan Balakumar: Conceptualization, Writing – review & editing; **Narayanan Mahesh**: Conceptualization, Writing – review & editing; **Murugesan Kamaraj**: Writing – original draft; **S. Shyamalagowri**: Writing – review & editing; **J. Manjunathan**: Writing – review & editing; **S. Murugesan**: Writing – review & editing: **J. Aravind**: Conceptualization, Writing, Editing and review; **P. Suresh Babu**: Conceptualization, Supervision, Writing – review & editing…

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