IOSR Journal of Applied Chemistry (IOSR-JAC)
e-ISSN: 2278-5736.Volume 16, Issue 12 Ser. I (December 2023), PP 21-23
www.iosrjournals.org

Photocatalytic Behavior of Metal Oxides

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Abstract: *A photocatalyst is a substance that facilitates chemical reactions when exposed to light, typically ultraviolet (UV) or visible light. Photocatalysts are essential components in various applications, including environmental remediation, water purification, hydrogen production, and solar energy conversion. Metal oxides have proven to be invaluable materials in the realm of economic and environmental applications. Hence, understanding their behavior in photocatalysis is crucial for harnessing their potential in addressing pressing global environmental challenges. The use of metal oxide nanocomposites (MON), from the mixture of two or more oxides or between these oxides and other functional semiconductor materials, have gained increasing attention from researchers and industrial developers as a potential alternative to produce efficient and environmentally friendly photocatalysts for the remediation of water contamination by organic compounds. Thus, this work presents an updated review of the main advances in the use of metal oxide nanocomposites-based photocatalysts for decontamination of water polluted by these substances.*

Keywords: *Photocatalysis, Photodegradation, nanocomposites, Environmental Remediation*

I. Introduction

Primary treatment of wastewater, using filtration and sedimentation, generally captures only larger particles. The smaller particles remain in the water, with the need for additional costs in a water treatment plant to arrange other decontamination methods in order to lessen the problem. Among the alternative techniques, it is possible to mention chemical oxidation, other filtration processes (using sand and biological filters), membrane separation, adsorption of the compounds with activated carbon, and ozonation

Health, energy and the environment are the most crucial factor in the social and economic growth and overall well-being of any nation. The wide spread use of fertilizers, pesticides, solvents, and similar substances in extensive agricultural practices and industrial activities is becoming an ever increasing problem and thereby causing huge concern within the global scientific communities and regulatory bodies. The toxicity and the resistance to degradation of these chemicals possess serious threats to both the human health and environment, contributing substantially to ecological disruption in aquatic and non-aquatic ecosystems. Photocatalysis is one of the promising methods for the detoxification of diverse hazardous pollutants and for the environmental remediation. A photocatalyst is a substance that facilitates chemical reactions when exposed to light, typically ultraviolet (UV) or visible light. It works by absorbing photons and using their energy to initiate or accelerate chemical reactions. They are essential components in various applications, including environmental remediation, water purification, reduction of CO_2, and hydrogen production [1].

In recent times, researchers have explored a diverse array of semiconducting materials to serve as photocatalysts, expanding the horizons of this fascinating field. There are different materials which can be used as photocatalyst owing to their absorption property; metal oxides like Copper oxide (CuO), Magnesium oxide (MgO), Zinc oxide (ZnO), Iron oxide (Fe_2O_3), Vanadium oxide (V_2O_5), Bismuth oxide (Bi_2O_3), Tungsten oxide (WO_3) and Titanium dioxide (TiO_2) are commonly used as photocatalyst. Further, among all the above materials, TiO_2 is widely used because of its abundance in nature, low production cost, good chemical stability, non-toxic and environment friendly nature. Keeping view of above, understanding and optimizing the photocatalytic behavior of d-block metal oxides is important for harnessing their potentials to address the environmental challenges.

Fundamentals of Metal Oxides

Metal oxides belong to the group of semiconductor materials, which have chemical structures formed by the interaction of charges belonging to oxygen atoms (highly electronegative) with atoms of metallic elements. By definition, semiconductors have a structure composed of electronic bands, where the valence band (filled) is separated from the conduction band (unfilled) by a bandgap, with sufficient energy (around 1.0–3.0 eV) to maintain them with electrical insulators behavior at the temperature of 0 Kelvin

Metal Oxide based Photocatalyst

Photocatalysis processes can be homogeneous or heterogeneous. The heterogeneous photocatalysis process differs from the homogeneous one, due to the former's particularity of using catalysts in the solid state and, consequently, radicals are generated from the reactions between electron/hole (e−/h+) pairs with the medium, under the action of an incident light.

Extensive researches in the past few decades have shown that metal oxides have proven to be invaluable materials in the realm environmental applications, particularly when it comes to alleviate the problem of water pollution and decomposition of various wastes including organic and inorganic pollutants and solar energy conversion. For a better photocatalyst, materials should exhibit a significant capacity for light absorptionin visible region of the solar spectrum. This attribute allows it to capture and harness the energy from photons, initiating the catalytic process. Secondly, the material's structural morphology should be not only compatible with the desired reaction but also stable over time. In other words, it needs to maintain its form and structure under the conditions of the photocatalytic reaction, ensuring consistent performance.

Titanium Dioxide based photocatalyst

In 1972, Honda and Fujishima performed electrolysis of water by using $TiO_2$to electrolyze water intoH_2 and O_2. TiO_2exhibits remarkable characteristics, including a high exciton binding energy, excellent photocatalytic performance, and an adaptable crystal structure When exposed to ultraviolet (UV) light, TiO_2 nanoparticles become excited, causing their electrons to transition from the valence band to the conduction band. This transition leaves a hole behind in the place where the electron previously resided. Following photoinduction, the pair produces active O_2^- and OH radical species. These active species carry out the redox reaction with organic contaminants.Despite its promising applications; the application of TiO_2 is restricted in the visible light photocatalysisdue to its large bandgap and rapid recombination of electron and hole pairs. Therefore, to overcome these limitations of TiO_2, researchers have adopted various strategies to improve its photocatalytic performance. When platinum (Pt) is doped with TiO_2, it increases the charge separation phenomenon. Some nanocomposite of this metal oxides are TiO_2/SiO_2, TiO_2/Al_2O_3, and TiO_2/B_2O_3.

Iron Oxide based photocatalyst

Iron oxide based photocatalysts are used for the degradation of water and removal of organic pollutants. There are three common forms of iron oxide i.e. magnetite Fe_3O_4 , hematite α-Fe_2O_3, and maghemite γ-Fe_2O_3. Iron oxide nanoparticles have supermaganetic properties and biocompatibility. The distinct magnetic characteristics of iron oxides open up exciting possibilities in various fields, finding practical use in magnetic resonance imaging (MRI), biosensing applications, and storage devices.

The three aforementioned types of iron oxides are commonly employed due to their ability to undergo phase transitions in response to temperature changes, demonstrating significant polymorphism. Hematite (α-Fe_2O_3) possess weak feromagnetism and low saturation magnetization. On the other side Fe_3O_4 and γ-Fe_2O_3 have high magnetization in compare to (α-Fe_2O_3). Characteristics such as magnetism, magnetic moment, and photocatalytic behavior exhibit a size-dependent nature. This means that when the size of nanoparticles composed of these oxides is altered, they exhibit distinct dipole moments. Iron oxide nanoparticles can be effectively combined with other substances to obtain the heightened photocatalytic performance. When iron oxide is doped with TiO_2 then it shows magnetic recoverability of iron oxide. The intricate nanostructure topography, coupled with the resonance of plasmonic effects, substantially augments optical absorption, further boosting its performance.

Magnesium Oxide based photocatalyst

Magnesium oxide nanoparticles possess a broad band gap, distinctive physicochemical attributes, and a substantial specific surface area. MgO has found applications in a variety of fields, including pharmaceuticals, cement industries, optics, and numerous other sectors. It is preferred over ZnO and TiO_2 because of its low cost and availability [8]. MgO can be effectively utilized for the degradation of toluidine blue (TB) dye. The success of this process depends on a combination of factors, including the pH of the TB solution, the concentration of TB, and the quantity of MgO applied. In practical terms, when we increase the quantity of MgO, we expand the active sites of this photocatalyst. As a result, this augmentation leads to a higher production of hydroxide ions (OH^-) radicals.

II. Conclusion

The discussion of recent advances on the use of metal oxide nanocomposites demonstrated that most water decontamination processes involving these nanocomposites are carried out with visible light. This shows that charge transfer in the final semiconductor is facilitated by the presence of additional energy levels resulting from the interaction at the electronic level of these materials, which directly originates lower electron/hole recombination rates and facilitates the charge transport. A suitable photocatalyst material should exhibit a significant capacity of absorption of larger fraction of the solar light. The effectiveness of the photocatalytic properties depends on their physical and chemical characteristics, so, doping of other metal can enhance the photocatalytic activity of metal oxides. Despite the significant progress achieved in study of metal oxides, further research is needed to address the existing challenges and drawbacks and to realize their potential in photocatalysis.

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