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EDITORIAL ARTICLE

Metal oxides as photocatalysts

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Abstract Metal oxides are of great technological importance in environmental remediation and electronics because of their capability to generate charge carriers when stimulated with required amount of energy. The promising arrangement of electronic structure, light absorption properties, and charge transport characteristics of most of the metal oxides has made possible its application as photocatalyst. In this article definition of metal oxides as photocatalyst, structural characteristics, requirements of the photocatalyst, classification of photocatalysts and the mechanism of the photocatalytic process are discussed.

Photocatalysis is a science of employing catalyst that is utilized for speeding up chemical reactions that requires or engages light. A photocatalyst is defined as a material that is capable of absorbing light, producing electron–hole pairs that enable chemical transformations of the reaction participants and regenerate its chemical composition after each cycle of such interactions [1–6]. There are two types of photocatalytic reactions i.e. homogeneous photocatalysis and heterogeneous photocatalysis.

The significant features of the photocatalytic system are the desired band gap, suitable morphology, high surface area, stability and reusability [3–6]. Metal oxides such as oxides of vanadium, chromium, titanium, zinc, tin, and cerium having these characteristics follow similar primary photocatalytic processes such as light absorption, which induces a charge separation process with the formation of positive holes that are able to oxidize organic substrates [4–6]. In this process, a metal oxide is activated with either UV light, visible light or a combination of both, and photoexcited electrons are promoted from the valence band to the conduction band, forming an electron/hole pair (e-/h+). The photogenerated pair (e-/h+) is able to reduce and/or oxidize a compound adsorbed on the photocatalyst surface. The photocatalytic activity of metal oxide comes from two sources: (i) generation of $^{\bullet}OH$ radicals by oxidation of OH^- anions, (ii) generation of O_2^- radicals by reduction of O_2. Both the radicals and anions can react with pollutants to degrade or otherwise transform them to lesser harmful byproducts [5,6].

There are many catalysts reported in the literature for this exciting process. Among these metal oxides (TiO_2, ZnO, SnO_2 and CeO_2), which are abundant in nature, have also been extensively used as photocatalysts, particularly as heterogeneous photocatalyst since several decades [5–7]. This is because of their biocompatibility, exceptional stability in a variety of conditions and capability to generate charge carriers when stimulated with required amount of light energy. The favourable combination of electronic structure, light absorption properties, charge transport characteristics and excited lifetimes of metal oxides has made it possible for their application as photocatalyst [2–6,8]. Heterogeneous photocatalysis employing metal oxides such as TiO_2, ZnO, SnO_2 and CeO_2 has proved its efficiency in degrading a wide range of distinct pollutants into biodegradable compounds and eventually mineralizing them to harmless carbon dioxide and water [9–18].

Recent research has also shown that (Fig. 1) metal oxides can be used as a photocatalyst to decompose toxic organic compounds, photovoltaics, prevent fogging of glass and even split water into hydrogen and oxygen [2–6]. Hence, they are of great technological importance in areas of environmental remediation, storage, hydrogen production and electronic industries [3–6]. The heterogeneous photocatalysis is also being actively investigated (Fig. 1) as a promising self-cleaning, antibacterial and deodorization system [3–6]. The applications of such photocatalytic process are mostly needed for the purification of waste water, by removal of bacteria and other pollutants, as this can render water reusable.

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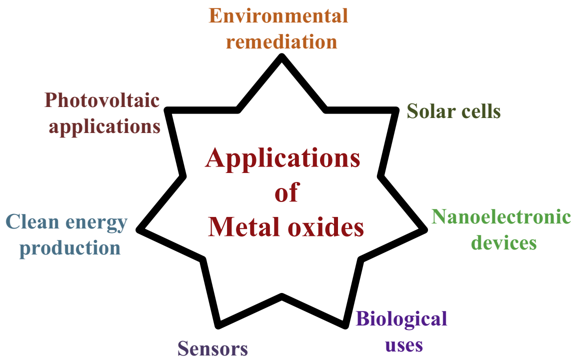

Figure 1 Possible applications of metal oxides.

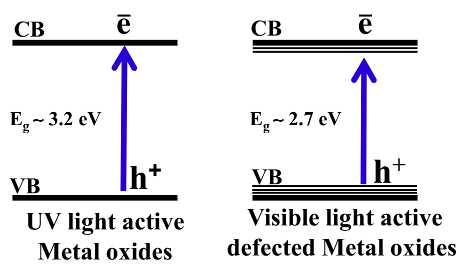

Figure 2 UV light active metal oxides and visible light active metal oxides showing photo excitation.

Among oxidation reactions, most of the photocatalytic processes, are focused on the conversion of highly toxic chemicals to either less toxic chemicals or CO_2 and H_2O [4–6,8–10]. These properties make metal oxides an effective photocatalyst for degradation of environment pollutants. When the photocatalytic oxidation reaction is carried out in the presence of O_2, the catalyst not only plays a role in scavenging the photogenerated electrons but also produces active oxygen species. Apart from the UV-light activated photocatalyst, it was recently reported that the defected metal oxides could also respond to visible light (Fig. 2), a process which is termed as visible light-induced photocatalysis widely employed for environmental remediation [11–13,17,18]. This is another milestone in the field of photocatalysis.

The physicochemical properties of the metal oxides are crucial for the virtuous photocatalytic performance, which are typically size, shape, morphology, and composition dependent [2–5,14,16]. The synthetic procedure employed can control the size, shape and morphology of the materials prepared, which can contribute towards the development of certain properties of the photoactive materials. This can facilitate the formation of powders or thin films with the required characteristics that improve the performance of the catalyst [6,14,16,19–21]. It is also the source and type of the light used that can affect the performance of the material as a photocatalyst [8–10].

Hence, in conclusion, knowledge of the different synthetic procedures employed for the preparation of photocatalytic materials should be considered necessary. The search for new photocatalysts having desired characteristics to induce the oxidation of organic substrates or pollutants under visible light irradiation is encouraging. The metal oxides should be ecologically affable and preparation via inexpensive routes should be the main attention. These are the major concerns from the synthetic and industrial points of view which should be the primary focus of the researchers involved.

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