Metal Oxide Applications

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Metal oxides play a key role in environmental remediation.

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1. Introduction

Metal oxides play a key role in environmental remediation and pollutant sensing and are strategic also in several other applications including energy production, conversion and storage. Metal oxides exhibit a great variety of functional properties, strongly dependending on their crystal structure, morphology, composition, intrinsic defects, doping, etc., which determine their optical, electrical, chemical and catalytic properties. Growth methods and process parameters strongly govern the morpho-structural characteristics and therefore the physico-chemical properties of metal oxides[1][2]. The band gap and electronic structure of oxides can be controlled and tailored by the size and dimension and this is the key to multifunctional possibilities presented by metal oxide-based materials. Modulating the bandgap and surface adsorption properties is essential for application in heterogeneous photocatalysts. The structural diversity of metal oxides is provided by both chemical and physical methods of synthesis, and by the process parameters. A lot of work has been reported in the green synthesis of metal oxide-based materials[3]. Recently, metal oxides' synthesis assisted by ionic lliquids (ILs) has been proposed to achieve oxides' production with controllable nanostructures (nanorods, nanospheres, core-shell nanostructures, etc.) and increased catalytic efficiency for air pollutant sensing and remediation. ILs ability to dissolve inorganic compounds can play a noteworthy role in producing highly dispersed composites, enhancing their activity[4].

The release of toxic and often difficult to degrade chemicals from industries producing pharmaceuticals, textiles and paints leads to large-scale water and soil pollution. In this regard, metal and metal oxide nanoparticles have been known to exhibit good photocatalytic properties for the degradation of such chemicals. An environmental remediation photocatalyst works by facilitating oxidation and reduction processes via trapping the light energy which leads to quick degradation of the targeted pollutants. Apart from common organic pollutants like dyes, other organic pollutants like antibiotics, PAHs, pesticides, and non-organic species such as heavy metals, radioactive metal compounds, sulfur compounds, and inorganic contaminants also need to be removed from water bodies. Environmental remediation also involves effective measures to monitor the levels of these pollutants in soil, water and air[5][6][7][8].

Concerning the energy applications, the photoelectrochemical (PEC) water splitting and the photocatalytic reduction of CO_2 represent environmentally friendly and sustainable sources of hydrogen fuel and renewable fuels and chemicals, respectively. Metal oxide semiconductors play a key role in both applications, due to their photo-electrochemical stability, low cost, favorable band edge positions and bandgaps.

2. Applications of Metal Oxide

As one of the most sought-after fields of research due to the scope of structural and functional variation that can be produced, metal oxides continue to be explored for the environmental remediation, for solving the energy crisis and for decarbonization.

However, the challenges provided by the actual implementation need to be solved effectively. Finding organic ligands, metal oxides, solvents, dopants and other chemicals with low cost and the least environmental impact remains a challenge. At the same time, the most positive aspects of metal oxide-based materials remain the easy tuning of their bandgaps for photocatalytic purposes. The degradation of dyes, antibiotics, and pesticides do show much promise toward remediation of wastewaters, as does the photoreduction of CO2. Overall, this field of research shows the potential for growth in a future tuned toward smart materials for energy and environmental sustainability.

Metal oxides play a key role in decarbonization strategies and have become an important factor in industrial expansion, along with the invention of new catalytic methods for carrying out non-thermal reactions, energy storage methods and environmental remediation through the removal or breakdown of harmful chemicals released during manufacturing processes. The scalabalility from laboratory to industrial scale is one of the major aspects that needs to be looked at, when considering the metal oxide-based materials. Large-scale production is necessary in order to fulfill the goals of environmental remediation, decarbonization and energy sustainability. The points that need to be considered while formulating metal oxide-based materials as photocatalysts for commercial purposes can be summarized as follow:

a. Availability and cost of precursor metals, their oxides, and other auxiliary materials for their synthesis;
b. Toxicity of the metals/metal oxides, auxiliary materials and pollution caused while producing these;
c. Energy-efficient batch production;
d. High specific surface area and well-tuned bandgap for efficient adsorption and catalytic activity;
e. Ability to work under sunlight or other forms of visible light;
f. Possibility of addressing multiple environmental pollutants and/or energy storage and conversion strategies.
g. Easy recovery and recyclability of the photocatalysts.

However, many of the metal oxide systems reported in the literature suffer from a high economic cost of manufacturing. Out of a plethora of metal oxide-based nanoparticles reported thus far, ZnO and TiO2 have found their way into commercial applications, while iron oxide-based materials are also being explored owing to their easy magnetic separation[9][10][11][12][13][14][15].

Concerning the production of renewable energy, still some drawbacks need to be overcome. For instance, all the investigated metal oxides photoelectrodes suffer from low STH conversion efficiency and low long-term stability due to chemical dissolution, electrochemical corrosion, and photocorrosion, and CO2-derived fuels are actually not competitive to fuel oils due to their high economic costs.

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