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Review

Photocatalytic materials and technologies for air purification

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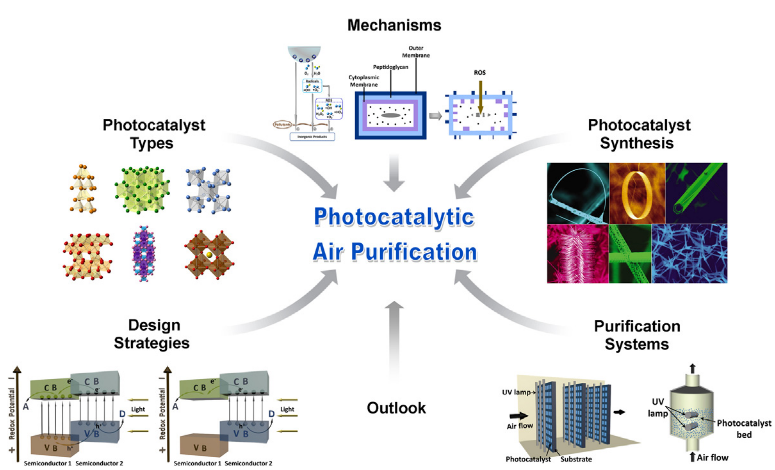
HIGHLIGHTS

- Mechanisms of photodegradation and photodisinfection.
- Reported system designs for photocatalytic air purification.
- Established and recently developed photocatalysts for air purification.
- Methods of synthesis of photocatalysts for air purification.
- Recent strategies to enhance the efficiencies of photocatalysts.

GRAPHICAL ABSTRACT



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ABSTRACT

Since there is increasing concern for the impact of air quality on human health, the present work surveys the materials and technologies for air purification using photocatalytic materials. The coverage includes (1) current photocatalytic materials for the decomposition of chemical contaminants and disinfection of pathogens present in air and (2) photocatalytic air purification systems that are used currently and under development. The present work focuses on five main themes. First, the mechanisms of photodegradation and photodisinfection are explained. Second, system designs for photocatalytic air purification are surveyed. Third, the photocatalytic materials used for air purification and their characteristics are considered, including both conventional and more recently developed photocatalysts. Fourth, the methods used to fabricate these materials are discussed. Fifth, the most significant coverage is devoted to materials design strategies aimed at improving the performance of photocatalysts for air purification. The review concludes with a brief consideration of promising future directions for materials research in photocatalysis.

Contents

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1. Introduction

There is increasing concern for the impact of air quality on human health. According to the World Health Organization (WHO) reports and the literature [1–4], air pollution is defined as the contamination of outdoor or indoor air by organic and inorganic chemical contaminants, including:

- Gaseous organic and inorganic chemical contaminants:
  - Volatile organic compounds (VOCs)
  - Carbon monoxide (CO)
  - Nitrogen-containing compounds (NO_x)
  - Sulfur-containing compounds (SO_x)
- Pathogens:
  - Bacteria
  - Viruses
  - Fungi
- Particulate matter:
  - Solid organic and inorganic pollutants
  - Pathogens

Many of these species are derived from the burning of fuels, potentially causing chronic respiratory and pulmonary diseases as well as cardiopulmonary and lung cancers. According to a 2014 WHO health report [5], global deaths from air pollution in 2012 were approximately 7 million, of which 3.7 million were from outdoor pollution and 4.3 million were from indoor pollution, of which 1.0 million were from a combination of the two. The large majority of these deaths were in third-world regions. In addition to the health concerns, there also are natural environmental concerns in that air pollution also affects the survival and welfare of native flora and fauna. Further, the built environment can be affected deleteriously through the effects of acid rain and fungal growth.

Air pollution can be addressed through the two approaches of prevention and removal. Strategies for the former include the use of alternative fuels, improved industrial processes and efficiencies, and improved sanitation. At present, the most common methods for the removal of air pollutants are filtration and adsorption, such as electrostatic air purification, air filtration, and gas adsorption filtration [6,7]. However, it may be noted that a potential shortcoming is that these methods involve physical removal and so require material replacement, cleaning, and disposal. In contrast, the potential to decompose pollutants can eliminate these additional requirements. In consequence, ultraviolet radiation and ozone disinfection have emerged as the most commonly used techniques for destroying pathogens, although these have the disadvantages of being harmful to human health [7–9]. Therefore, there is a critical need to develop an effective, safe, and inexpensive technique to decompose as wide a range of air pollutants as possible.

Photocatalysis is one of the most promising methods that can be used for air purification. The seminal work on photocatalysts by Fujishima and Honda [10] led to initial studies in the destruction of liquid organic compounds by a semiconducting photocatalyst (TiO_2), including polychlorobiphenyls [11], chloromethanes [12,13], trichloroethylene [14], and dichloroacetaldehyde [14]. In addition, Matsunaga et al. [15] were the first to demonstrate the use of photocatalysis for disinfection of pathogens, including *Lactobacillus acidophilus*, *Saccharomyces cerevisiae*, and *Escherichia coli*.

Photocatalytic materials and technologies for air purification are based largely on the principle that radiation of suitable wavelengths can be absorbed by many semiconductors, which facilitates the creation of reactive oxygen species (ROS) that can decompose air pollutants.

The simplicity, flexibility, and effectiveness of such photocatalytic devices for air purification offer unique advantages [16,17]: