ISSN 2959-6157

Current status of TiO_2 photocatalytic reduction of carbon dioxide

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Abstract:

this study summarizes the current research status and development trend of TiO2 photocatalytic reduction of carbon dioxide, including the reaction mechanism, metal-loaded TiO2, semiconductor composite TiO2, and organic photosensitizer-modified TiO2, and shows that the metal-loaded TiO2 enhances the catalytic activity, and in particular, copper-loaded catalysts on the surface of TiO2 have the potential. Semiconductor composite TiO2 enhanced the photogenerated carrier transport efficiency and improved the catalytic activity. Modification of TiO2 with organic photosensitizers can improve the photocatalytic efficiency, but challenges such as stability and light absorption efficiency need to be addressed.

Keywords: TiO2 photocatalysis, CO2 reduction, photogenerated carriers, redox capacity, research status

1. Introduction

In the current context of global warming, carbon dioxide emissions have always been considered one of the major greenhouse gases and have had a non-negligible impact on the global environment. Climate warming has led to frequent extreme weather events, rising sea levels, and threats to ecosystems, posing huge challenges to human society and the economy. Therefore, it is particularly important to explore effective carbon dioxide emission reduction and utilization technologies. The TiO_2 photocatalytic reduction of carbon dioxide technology has attracted much attention as a potential environmentally friendly method. TiO_2 is recognized as one of the most promising environmentally friendly catalysts due to its advantages such as safety, non-toxicity, high activity, resistance to chemical and photocorrosion, and low cost[4]. Based on these advantages, TiO_2 shows potential application prospects as a photocatalyst in the reduction of carbon dioxide.

Photocatalytic reduction of carbon dioxide can convert light energy into chemical energy and convert carbon dioxide into high value-added chemicals or fuels, effectively reducing greenhouse gas emissions. This article will summarize the research status, development trends and applications of TiO_2 photocatalytic reduction of carbon dioxide technology in existing research. Through the comparison and summary of research on different catalysts, we can gain a more comprehensive understanding of the current research status of TiO_2 photocatalytic reduction of carbon dioxide technology.

2. Reaction Mechanisms

The mechanism of TiO_2 photocatalytic reduction of carbon dioxide is based on TiO_2 as a semiconductor material. TiO_2 can absorb energy under light irradiation. According to the wavelength of absorbed light, it can be inferred that CO_2 is mainly reduced by photoelectrons excited by the photocatalyst [6]. The excited electrons jump from the valence band to the conduction band, and holes are formed in the valence band at the same time. Form electron-hole pairs. These photogenerated carriers have oxidation and reduction capabilities [18-20, 24], participate in the photocatalytic reduction reaction of CO_2, and reduce CO_2 to organic compounds. It is worth noting that these photogenerated carriers are unstable and prone to recombination reactions. Therefore, improving the utilization efficiency of photogenerated carriers is an important topic in the research of TiO_2 photocatalytic reduction of CO_2.

In TiO_2 catalysts, current research shows that TiO_2 has three crystal forms in nature: rutile, anatase and brookite. The difference in crystal form often leads to different reactivity in photocatalytic reduction of CO_2 [3, 23]. The anatase crystal form of TiO_2 has high photocatalytic activity, mainly due to its high band gap and surface adsorption capacity [14]. The anatase crystal form has higher photocatalytic activity for the following reasons: the band gap of the anatase crystal form is 3.2 eV, while the band gap of the rutile crystal form is 3.0 eV. The high forbidden band width of the anatase crystal form is The band width allows its electron-hole pairs to have higher or lower potentials, thus having strong oxidizing ability [3]. In addition, the small grain size and large specific surface area of anatase TiO_2 also play a positive role in the photocatalytic activity. As studied by Akple et al., the crystalline surface heterostructure will have an impact on the degree of electron-hole separation and catalytic activity [1].

In addition, the advantages and limitations of a single TiO_2 catalyst in CO_2 photocatalytic reduction are also one of the focuses of research. Although TiO_2 has certain redox capabilities, its photocatalytic reaction has low quantum efficiency, which may limit its efficiency in practical applications. Therefore, in future research, methods to improve the photocatalytic efficiency of TiO_2 need to be further explored to achieve more effective CO_2 reduction conversion.

3. Research status of different catalysts

3.1 Metal-loaded TiO_2 photocatalysts

The research progress of metal-supported TiO_2 photocatalysts in the photocatalytic reduction of carbon dioxide has attracted increasing attention. By loading metal on the surface of TiO_2, the energy level structure and surface active site density of the catalyst surface can be adjusted, thereby improving the photocatalytic activity and selectivity and promoting the conversion of CO_2. When studying metal-supported TiO_2 photocatalysts, factors such as metal type, loading method, catalyst structure, and photocatalytic performance need to be considered. Transition metals such as copper (Cu[12, 13, 21, 22]) and platinum (Pt[13, 21, 22]) show good activity and stability in CO_2 photocatalytic reduction. Studies have pointed out that the emergence of low-priced copper plays a key role in the formation of Cu^+/Cu^{2+}, which in turn improves the photocatalytic redox performance of the catalyst [2]. It can be seen that the catalyst with Cu supported on the surface of TiO_2 has great potential in the photocatalytic reduction of CO_2. Comparing the performance of different metal-supported TiO_2 catalysts can reveal the advantages and disadvantages of various catalysts and provide guidance for further research. In addition, the performance and applications of different metal-supported TiO_2 catalysts also need to be compared and evaluated. By comparing the photocatalytic activity, selectivity, stability and other performance parameters of different metal-supported TiO_2 catalysts, the advantages and disadvantages of various catalysts can be revealed.

In the future, the development trend of metal-supported TiO_2 photocatalysts will mainly focus on improving catalytic efficiency, expanding application scope and improving stability. Through advanced catalyst design and preparation technology, metal-supported TiO_2 catalysts are expected to play a more important role in the field of CO_2 photocatalytic reduction. Future research should focus on the optimization of catalyst structure, improvement of metal loading methods and in-depth exploration of photocatalytic mechanisms to achieve the goal of more efficient conversion of CO_2 into renewable fuels.

3.2 Semiconductor Composite TiO_2 Photocatalysts

Research on semiconductor composite TiO_2 photocatalysts in CO_2 photocatalytic reduction has attracted increasing attention. By combining semiconductor materials with TiO_2, the separation and transmission of photogenerated carriers can be achieved, thereby improving photocatalytic efficiency and selectivity and promoting the conversion of CO_2. When studying semiconductor composite TiO_2 photocatalysts, factors such as the type of semiconductor material, composite method, photoelectric performance, and synergistic effect with TiO_2 need to be comprehensively considered.

Among semiconductor composite TiO_2 photocatalysts, common semiconductor composites include composites of titanium dioxide and other semiconductor materials, such as zinc oxide (ZnO), gallium nitride (GaN), etc. The formation of these complexes can effectively expand the photoresponse range of TiO_2, and the semiconductor composite TiO_2 can effectively separate the photogenerated electron-hole pairs of the catalyst [8-11, 13, 16], thereby enhancing the photocatalytic activity of the catalyst [7].

However, with the in-depth research on composite materials, there are also some challenges, such as the appropriate proportion control of composite materials and the effective separation and transmission of photogenerated carriers. Therefore, in future research, it is necessary to further explore the optimized design, combination method selection and stability improvement strategy of semiconductor composite TiO_2 photocatalysts to achieve the goal of more efficient conversion of CO_2 into renewable energy. In summary, the semiconductor composite TiO_2 photocatalyst, as a new type of photocatalytic material, has great potential in CO_2 photocatalytic reduction. Through in-depth study of its photocatalytic mechanism, influencing factors and performance optimization paths, important theoretical and practical guidance can be provided for future green energy development and environmental governance.

3.3 Organic photosensitizer modification

Modification of TiO_2 with organic

Photosensitizers is a common strategy used to improve TiO_2 photocatalytic activity and selectivity, especially for applications in CO_2 photocatalytic reduction. Since the excited state potential of the photosensitizer used needs to be more negative than the conduction band potential of TiO_2, the excited electrons can be injected into the conduction band of TiO_2; the catalyst uses the electrons injected into the conduction band to reduce CO_2 [7]. By introducing organic photosensitizers, the light absorption range of TiO_2 can be expanded, the generation and utilization of photogenerated carriers can be promoted, and the photocatalytic reaction efficiency can be enhanced.

In the process of studying the modification of TiO_2 with organic photosensitizers, some key organic photosensitizers such as phthalocyanine compounds, azo dyes, etc. have been widely studied. By interacting with the TiO_2 surface, these organic photosensitizers can effectively regulate the surface energy level structure of TiO_2 and improve the separation efficiency of photogenerated electron-hole pairs. The introduction of organic photosensitizers can not only enhance the light absorption capacity of TiO_2, but also regulate the selectivity and product distribution of the photocatalytic reaction.

However, TiO_2 modified with organic photosensitizers also faces some challenges, such as the stability of the organic photosensitizer, light absorption efficiency, and separation efficiency of electron-hole pairs generated by photolysis and absorption. Therefore, in future research, it is necessary to further explore the interaction mechanism between different types of organic photosensitizers and TiO_2, and optimize the method of modifying TiO_2 with organic photosensitizers to achieve more efficient photocatalytic reduction and conversion of CO_2.

In summary, modifying TiO_2 with organic photosensitizers is an effective way to improve the photocatalytic performance of TiO_2, and has potential application prospects in the photocatalytic reduction of CO_2. In-depth study of the mechanism and influencing factors of TiO_2 modification by organic photosensitizers can provide important inspiration for the development of photocatalytic technology and promote research progress in converting CO_2 into renewable energy.

3.4 Non-metal doping

Non-metal doping is one of the effective strategies to improve the performance of TiO_2 photocatalyst. During the reduction process of carbon dioxide, non-metallic elements such as nitrogen [16-18] (N), sulfur (S), phosphorus (P), etc. are introduced into the TiO_2 crystal lattice, which can change its electronic structure and light absorption characteristics. This doping helps expand the photoresponse range of TiO_2 to the visible light region and improves its ability to utilize sunlight. Through non-metal doping, the effective separation of photogenerated charges can be promoted, the recombination of electron-hole pairs can be reduced, and the photocatalytic activity can be increased. In addition, non-metal doping can also improve the stability of the catalyst and the selectivity of carbon dioxide reduction products.

For example, nitrogen-doped TiO_2 can change the band gap of TiO_2 so that it can absorb more visible light and enhance its ability to photocatalytically reduce carbon dioxide. Similarly, sulfur-doped TiO_2 also shows excellent photocatalytic performance because sulfur can serve as an electron capture center and promote electron transfer. However, it is worth noting that the larger the doping amount, the better. Too much doping will Impurities will form an electron-hole pair recombination center on the catalyst surface, accelerating the electron-hole pair recombination, which is not conducive to the progress of the catalytic reaction [5].

In general, non-metal doping is a promising method that can significantly improve the performance of TiO_2-based photocatalysts in reducing carbon dioxide, help develop more efficient photocatalysts, and provide solutions to the energy crisis and global warming issues. new ideas. At the same time, technical challenges lie in the unclear reaction mechanism of non-metal ion doping, which poses theoretical obstacles to further research, and the poor stability of TiO_2 after non-metal doping.

4. Conclusion

Existing literature has deeply discussed the research status and key issues of TiO_2 photocatalytic reduction of carbon dioxide technology. Through a comprehensive analysis of the research status of different catalysts such as metal-supported TiO_2 photocatalysts, semiconductor composite TiO_2 photocatalysts, organic photosensitizer-modified TiO_2, and non-metal doping, we found that various modification methods have an impact on the photocatalytic performance of TiO_2 Significant influence. TiO_2 catalysts will also inevitably develop towards new TiO_2 catalysts with higher light source utilization, higher quantum yield, and greater photocatalytic activity.

Based on the review and analysis of the literature, the future development trends and research directions of TiO_2 photocatalytic reduction of carbon dioxide technology have become clearer. I believe that future research should focus on the refinement of catalyst structure design and performance optimization, and explore the synthesis of new catalysts and their application in CO_2 photocatalytic reduction to improve photocatalytic activity and quantum efficiency and achieve efficient use of renewable energy. . In addition, it is necessary to strengthen the in-depth understanding of the photocatalytic reaction mechanism, and gradually reveal the reaction mechanism of photocatalytic reduction of CO_2 through research methods that combine different detection methods, so as to achieve precise control of reaction conditions, products and yields.

In summary, TiO_2 photocatalytic reduction of carbon dioxide technology is of great significance in combating climate warming and reducing carbon dioxide emissions. Our research provides useful reference and inspiration for the future development of TiO_2 photocatalytic technology, and also lays the foundation for further exploration of research directions in the field of CO_2 photocatalytic reduction.

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