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The application of semiconductor nanomaterials in renewable energy

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Abstract. In the development of renewable energy, the usage of solar cells, fuel cells, hydrogen energy, thermoelectric energy, and thermal energy has become a significant focus of research and development. Semiconductor nanomaterials play important roles in these fields. This paper focuses on the usage of TiO_2 and In_2O_3 in renewable energy and finds out the trends and outlook of semiconductor nanomaterials in this field. TiO_2 nanomaterials have attracted widespread attention due to their unique structure and excellent properties, such as their large specific surface area, high surface activity, and sensitivity. TiO_2 nanomaterials are highly active in photovoltaic applications and play an important role in the search for renewable, clean energy technologies. In_2O_3 is an excellent n-type transparent semiconductor functional material, characterized by high sensitivity, low resistivity, good conductivity, high catalytic activity, and wide bandgap width. It has shown good competitiveness in gas sensors, solar cells, and photocatalysis fields. Although these semiconductor nanomaterials have many advantages, there are still some drawbacks that hinder their development. There is still much work to be done for the wider application of semiconductor nanomaterials in the field of renewable energy.

Keywords: Nanomaterials, semiconductor, renewable energy, solar cell.

1. Introduction

The huge consumption of fossil fuels has been a major concern due to its detrimental effects on the environment and the limited availability of these resources. As economies continue to grow and technologies advances at an unprecedented rate, it becomes imperative to explore clean and sustainable alternative energy sources. Semiconductor nanomaterials have emerged as promising candidates in the field of renewable energy. In the realm of solar energy, the application of semiconductor nanomaterials has significantly improved the conversion efficiency of solar cells. And in energy storage systems, semiconductor nanomaterials reduce system energy consumption and improve energy utilization efficiency. The impact of semiconductor nanomaterials on renewable energy is increasing, and studying semiconductor nanomaterials will make important contributions to environmental protection and sustainable development [1]. This article delves into the extensive application of semiconductor nanomaterials in the field of renewable energy and conducts a comprehensive comparison with other materials commonly used. By exploring their advantages and disadvantages, it aims to provide valuable insights for the future development and utilization of semiconductor nanomaterials.

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2. Semiconductor nanomaterials

Semiconductor materials are a type of material with special electronic properties, with conductivity between conductors and insulators, which makes them widely used in the electronics industry. The conductivity of semiconductor materials can be controlled through doping and other means, making them the foundation of modern electronics and information technology. Semiconductor materials have been widely used in the field of renewable energy due to their advantages in improving energy conversion efficiency and promoting energy. Therefore, studying the properties of these materials is crucial for the design and optimization of electronic devices for renewable energy.

In the field of materials, the study of nanostructures has far-reaching implications. Due to the significant influence of size effects, nanostructures exhibit different electronic behaviours from macroscopic materials, such as the quantum confinement effect of quantum dots. The size of nanostructures is close to or smaller than the wavelength of light, leading to the manifestation of quantum properties of light, manifested as strong optical absorption and scattering behaviours. In terms of mechanics, nanowires exhibit high strength and elasticity.

3. Application of the semiconductor nanomaterials

3.1. Application of TiO_2 in renewable energy

Wen explored the structure of semiconductor nanomaterials, and found that silicon nanowires and gallium nitride nanostructures exhibit excellent electron transfer and optical properties [2]. And they have potential in the field of renewable energy. The application of nanotechnology in the field of semiconductor materials can promote the development of renewable energy, which means that semiconductor nanomaterials play an important role in renewable energy. Therefore, in-depth research on semiconductor nanomaterials is very urgent.

TiO_2 nanomaterials have received widespread attention due to their excellent properties, such as their large specific surface area and high surface activity. TiO_2 is a semiconductor material with good chemical stability, strong oxidation-reduction ability, and a wide range of sources. It has been widely used in fields such as photocatalytic oxidation, photocatalytic water splitting for hydrogen evolution, dye-sensitized solar cells (DSSCs), lithium-ion batteries, supercapacitors, etc. They are shown in figure 1. It plays an important role in developing new sustainable and environmentally friendly energy sources.

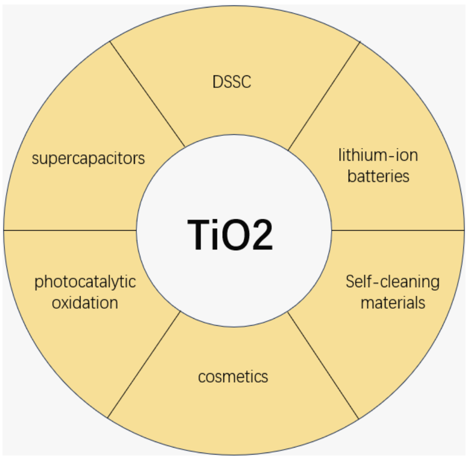

Figure 1. The application of TiO_2

DSSC is an important solar energy device, and compared to traditional silicon solar cells, DSSC has lower production costs and less environmental pollution. TiO_2 is widely used as an anode material for DSSCs due to its excellent charge transfer ability, stable chemical properties, and low cost. Ullattil used mesoporous rutile TiO_2 nanoparticles with a specific surface area of up to $210m^2/g$ as DSSC anodes [3]. Under 100% sunlight, the conversion efficiency of DSSC batteries reaches 6.6%, and the incident monochromatic photon electron conversion efficiency reaches 55% at a wavelength of 535nm. Mn^{2+}doped black rutile TiO_2 exhibits longer wavelength absorption in the infrared region of the solar spectrum [4]. Compared with commercially available P25TiO_2 manufactured DSSCs, it was found that the efficiency of black rutile TiO_2 in infrared absorption is 79% higher than that of commercially available P25 TiO_2. Tan obtained round cake shaped mesoporous TiO_2 with a specific surface area of 155.47 $m^2 \cdot g^{-1}$ through thermal decomposition of metal organic frameworks, which is three times that of P25 [5]. They mixed M- TiO_2 with P25 to prepare a photoanode. When the M- TiO_2 content reaches 50%, the open circuit voltage reaches its maximum value of 0.76V, and the highest photoelectric conversion efficiency of 2.03% is obtained.

Electrocatalytic oxidation technology is an advanced oxidation technology with strong oxidation-reduction ability, no secondary pollution, and easy control, used for the degradation of organic or inorganic pollutants. Boron-doped diamond film (BDD) anode has high oxidant generation ability, corrosion resistance, and high chemical stability, making it the most ideal anode for advanced electrocatalytic oxidation technology. However, the manufacturing process of BDD electrodes is complex and expensive, making them unsuitable for large-scale industrial applications. The TiO_2 nanotube electrode does not require expensive equipment or precious metal doping, has a low preparation cost, and has high oxygen evolution potential and good oxidant generation ability. It has great potential as an anode material. Kim synthesized a blue self-doped TiO_2 nanotube array electrode with excellent electrocatalytic activity through the cathodic method. The electrode has strong OH· and Cl_2 generation ability and its performance is comparable to BDD and shape stable electrode (DSA) with lower production costs [6]. Gan prepared a deep blue self-doped TiO_2 nanotube electrode (DNTA) through secondary anodization and cathodic polarization and used it for electrocatalytic oxidation degradation of phenol [7]. The results indicate that doping with Ti^{3+}can promote electron transfer and significantly improve conductivity. DNTA can generate a large amount of adsorbed OH · in electrocatalytic reactions, and under the same conditions, the mineralization rate of phenol is higher than that of BDD electrode. Yang prepared a blue black self-doped TiO_2 nanotube array (BNTA) electrode by electrochemical method and constructed a BNTA dual electrode electrocatalytic oxidation system [8]. The test results of electrocatalytic oxidation performance show that, compared with BDD electrode and titanium base iridium coated electrode (Ti/Ir), BNTA electrode material has lower energy consumption and chlorate generation rates.

3.2. Application of In_2O_3 in renewable energy

In_2O_3 nanomaterials have attracted widespread attention due to their superior optoelectronic properties and excellent electronic transport capabilities. In_2O_3 nanomaterials have become a focus of research in the field of solar cells. Lan prepared flexible amorphous transparent V-doped In-Zn-O (IZVO) thin films with different vanadium (V) atomic concentrations at room temperature [9]. The films have the characteristics of low resistance (about 22.6 Ω), high transmittance (about 88.8%), and high conductivity (2210 S/cm), exhibiting excellent electrode properties. At the same time, the flexible amorphous IZVO electrode has excellent mechanical flexibility and shows great potential in efficient flexible photovoltaic applications. Guo used low-temperature solvent combustion method to prepare In_2O_3 thin films, which were used as the electron transport layer of perovskite solar cells, with a power conversion efficiency of 18.12% and an electron mobility of up to 0.65 $cm^2/(v \cdot s)$ [10]. This material increases the charge transfer in the electron transport layer. Moghadamzadeh prepared a highly transparent hydrogen doped In_2O_3 electrode, and based on this electrode, the power conversion efficiency of solar cells reached 24.8%, showing good prospects for application in solar cells [11]. Dive found that the peak of the conduction band shift of indium gallium oxide alloy is 0.18 eV, which closely matches the optimal value of 0.2 eV [12]. Therefore, In_2O_3 and gallium oxide alloys can be applied to high-efficiency cadmium telluride thin film solar cells, achieving efficient conversion of solar cells.

Photocatalysis can degrade organic compounds with pollution into CO_2 and water. In_2O_3, due to its good conductivity and high transparency in the visible light range, with a transmittance of over 80%, can be applied in the field of photocatalysis. Zhao prepared mesoporous titanium dioxide/In_2O_3

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nanofiber photocatalysts by combining electrospinning and hydrothermal methods, with a specific surface area and pore volume of 45.5 m^2/g and 0.18 cm^3/g, respectively [13]. The large surface area and pore volume provide more active surface centres for photocatalytic reactions, thereby improving photocatalytic performance. Wang prepared D-In_2O_3 rich in oxygen vacancies by low-temperature NH_3 reduction of In_2O_3, and further surface modified AuNPs by gas film assisted reduction method to obtain Au/D-In_2O_3 composite catalyst for photocatalytic CO_2 reduction process using H_2O as reducing agent [14]. Due to the synergistic effect of oxygen vacancies and precious metal modifications, Au/D-In_2O_3 composite catalysts exhibit significantly enhanced visible light absorption, abundant CO_2 reduction adsorption activation sites, and excellent electron hole separation ability. The Au/D-In_2O_3 catalyst achieved a CO yield of 18.5 μ mol g^{-1} h^{-1} in the artificial photosynthetic reaction using H_2O as the proton donor, which is 23 times higher than the unmodified In_2O_3 catalyst, and the product selectivity reached 87%.

4. Advantages and disadvantages of semiconductor nanomaterials

The rapid development of industry has intensified the utilization of energy, leading to a sharp consumption of fossil fuels. Energy and resources have become important issues of close concern to countries around the world. The development of new energy and the rational utilization of resources are urgent. Semiconductor nanomaterials provide new methods to address the aforementioned issues. Semiconductor nanomaterials such as TiO_2 and In_2O_3 have been widely used in the field of renewable energy. TiO_2 nanomaterials have attracted widespread attention due to their unique structure and excellent properties, such as their large specific surface area, high surface activity, and sensitivity. The application of TiO_2 nanomaterials in solar cells has greatly improved the photoelectric conversion efficiency of solar cells, thereby minimizing energy loss and providing feasible ideas for the development of new energy. TiO_2 nanomaterials are highly active in photovoltaic applications and play an important role in the search for renewable clean energy technologies. In_2O_3 is an excellent n-type transparent semiconductor functional material with high sensitivity, low resistivity, good conductivity, high catalytic activity, and wide bandgap width. It has shown good competitiveness in gas sensors, solar cells, and photocatalysis fields. The application of In_2O_3 nanomaterials in solar cells can enhance the absorption of sunlight by solar cells, increase current output, and thus improve the efficiency of solar cells. Those semiconductor nanomaterials have been widely used in renewable energy, and it is still emergent to study the properties of these materials for the design and optimization of electronic devices in renewable energy.

Although these semiconductor nanomaterials have many advantages, there are still some drawbacks that hinder their development. Although In_2O_3 nanomaterials have excellent semiconductor properties and photocatalytic performance, they are usually in powder form and cannot be used alone. They need to be combined with other high-strength materials for practical and widespread application in fields such as solar cells and photocatalysis. Although TiO_2 nanomaterials have broad application prospects in environmental protection and new energy fields, their inherent physical and chemical properties limit the further improvement of their performance and the expansion of their application scope. TiO_2 nanomaterials have disadvantages such as narrow light absorption range, easy deactivation, and small specific surface area, which hinder their further development. There is still much work to be done for the wider application of semiconductor nanomaterials in the field of renewable energy.

5. Conclusion

This article summarizes the application of semiconductor nanomaterials in the field of renewable energy and explores the advantages and disadvantages of semiconductor nanomaterials. In addition to their larger specific surface area and improved photoelectric conversion efficiency, semiconductor nanomaterials have also demonstrated remarkable potential in various renewable energy applications. One such application is solar cell, where the use of semiconductor nanomaterials has led to significant advancement. Semiconductor nanomaterials also exhibit excellent moisture and heat resistance, maintaining good stability even under changing environmental conditions. However, the complex

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preparation process and high cost hinder the further development of semiconductor nanomaterials. In the future, research on semiconductor nanomaterials should focus on simplifying preparation processes, reducing preparation costs, and further improving photoelectric conversion efficiency, in order to further promote their widespread application in the field of new energy.

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