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Summary of Silicon and InGaN/GaN Solar Cells

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Abstract: With the global climate change, the continuous consumption of non-renewable energy and the improvement of human requirements for environmental protection, the concept of carbon emission has gradually become popular. One of the main ways to reduce carbon emissions is to use clean energy, among which solar energy is a kind of renewable clean energy that can be widely used. Based on the basic principle of solar cells and through the classification of solar cell materials, this paper introduces the research status of solar cells prepared by the first generation semiconductor silicon and the third generation semiconductor InGaN/GaN, and summarizes the main optimization methods and principles of solar cell efficiency. Silicon nanowire solar cells are rich in raw materials and easy to be prepared. They are the most widely used solar cells at present, but their efficiency is low and needs to be improved. The main method is to optimize their nanowire structure and material surface properties. InGaN/GaN nanowire solar cells can improve their photoelectric conversion efficiency by adjusting the In component, which is also the direction of improving the efficiency of the third generation semiconductor solar cells. Finally, the future development direction is proposed, which can provide the direction and basis for the efficiency optimization of nanowire solar cells.

1. Background

Since the 21st century, human beings are facing great demands for sustainable development in natural, social and economic aspects. At present, the large-scale use of fossil fuels contributes to global warming, which has aroused widespread concern on a global scale [1]. Therefore, under the premise of limited resources and the restriction of natural environment protection, reasonable economic development has become a hot topic.

At the current level of scientific and technological development, one of the renewable energy sources that can be widely used and inexhaustible is solar energy. According to the sustainable development strategy, solar energy will be the ideal alternative fuel in the world's energy mix of huge changes [2]. One of the main ways to use solar energy is through solar cells, which are used in photovoltaic power stations, household power supply, communications and meteorological fields. The key to the development of photoelectric technology is to reduce the production and maintenance cost and improve the photoelectric conversion efficiency of power generation [3].

Therefore, this article first clarified the basic principle of solar cells, introduced the current mainstream solar cell materials. It also specifically analyzes how to improve the conversion rate of solar cells, summarizes and sorts out the main methods and principles of improving solar cells at present. Finally, it prospected the direction of improving the efficiency of solar cells and the future development direction.

2. Principle

Solar cell is a kind of equipment that relies on green and clean electricity. It uses the photoelectric effect of semiconductor materials to convert solar energy into usable energy. When the sunlight hits the surface of the object, the charge distribution state inside the object will change, and the quasi-Fermi level separation occurs between the electron and the hole. The electromotive force and current are generated when the electron passes through the guide band, driving the load to work, as shown in Figure 1.

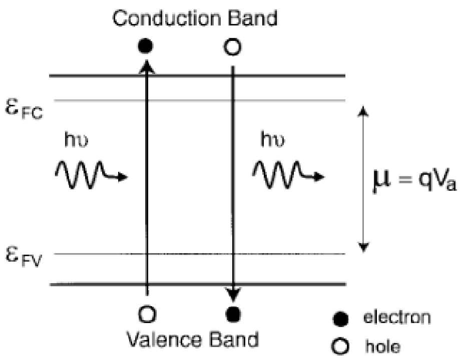

Figure 1: Generation and recombination of electrons and holes under photoelectric effect [4]

Most of the solar cells currently on the market are bulk silicon photovoltaics or bulk cells, because silicon material is relatively cheap and easy to obtain, it is the main leading product in the market. At present, the silicon solar cell industry has gradually become saturated and the process has been gradually improved. The first generation of solar cells using silicon wafers accounts for about 86% of the solar cell market, and their conversion efficiency is usually 11%-15% [5]. But the most important technical difficulty faced by silicon solar cells is the low efficiency of photoelectric conversion. The third generation of semiconductor solar cells, mainly based on gallium nitride, zinc oxide as typical wide bandgap semiconductor materials, generally speaking, this type of solar cells use less material than silicon-based solar cells, and theoretically have higher limit conversion efficiency [6] , as shown in Figure 2.

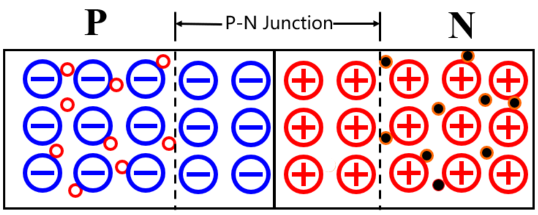

Figure 2: P-n junction of semiconductor materials

Because the first generation of semiconductor solar cells, or silicon solar cells, are the most widely used. The theoretical limit for third-generation semiconductor solar cells is higher, which can be applied to a wider range of environments, more high-end precision equipment. From a new perspective, this paper discusses the research status of solar cells based on the classification of the first generation semiconductor silicon and the third generation semiconductor InGaN/GaN.

3. Silicon solar cell

In the evolution of semiconductor material science, elemental semiconductors represented by silicon and germanium are called the first generation of semiconductor materials, in which the band gap width of silicon is 1.12eV. This section introduces the first generation of semiconductor solar cells represented by silicon. Silicon-based solar cells are classified into polysilicon and silicon nanowire solar cells according to materials [7]. At present, the main methods of polysilicon production in the world are SiHCl3, SiH4, SiH2Cl4, etc. [8].

The highest conversion efficiency of monocrystalline silicon solar cells is 26.7% [9]. At present, the highest conversion efficiency of polysilicon is developed by Astor company reported by Germany ISFH, and its efficiency reaches 22.8% [10].But because of the difference between the working environment and the laboratory, the conversion efficiency of polysilicon solar cells is usually only about 18% [6].

For the first generation of semiconductor solar cells, an important direction to improve their conversion efficiency is to reduce the reflectance of the device, and the main means to achieve this goal is to construct silicon nano-or micron structures. The nanowire solar cell will diffuse reflection when light irradiation to increase the time of light stays on the device, which is more favorable for light absorption. The main methods for producing silicon nanowires include electron beam lithography, metal-catalyzed gas-liquid-solid (VLS) method, supercritical liquid-solid (SFLS) synthesis method, solid-liquid-solid (SLS) growth method, oxide-assisted growth method, etc [11][12][13].Ge et al. from Nanjing University made a cell with an open-circuit voltage of 0.569V and a conversion efficiency of 9.3% by etching silicon with etching solution at room temperature [14].Y Zhang et al. from Soochow University designed a cell with an open-circuit current of 0.586V and an energy conversion efficiency of 13.8% using PEDOI:PSS and Si nanowires [15].

In addition to modifying silicon at the nanoscale, cell interface optimization is also a way to improve efficiency. By wrapping silicon nanowires to form a core-shell shape, Liang et al. accelerated charge collection and reduced interface recombination to improve device performance [16].Duan et al. from Yanshan University prepared solar cells by surface passivation and other methods by applying silicon nanowires micro-nano arrays with different filling rates, and obtained the highest efficiency of 13% [17].Ge et al. spin coated the synthesized cadmium telluride quantum dots between silicon nanowires and PEDOT: PSS to make hybrid solar cells with silicon nanowires/tablet cadmium quantum dots/PEDOT: PSS structure to improve the efficiency [15].Ma Guoliang et al. used V2O5, MoO3 and WO3 TMO films to passivate the phosphorus-doped silicon nanowires cell, which improved its absorption in the long-wave region and improved the open-circuit voltage and conversion efficiency [18].

4. Third generation semiconductor

The third generation semiconductor materials are represented by indium gallium nitrogen, gallium sulfide, silicon carbide, zinc selenide, etc. The band gap width of the composite can be continuously changed from 0.7eV of the InN band gap to 3.4eV of the GaN band gap by controlling the proportion of the composition of the alloy [19].This band gap covers the entire visible and part of the ultraviolet region [20].InGaN has a continuously adjustable band gap, while InN is free of the harmful chemical gases produced by GaAs and GAphosphate-based devices. Another advantage is that the special material properties of InGaN/GaN can counteract the extremely intense irradiation of high-energy electrons [21]. In addition, since the electronic band of InGaN material can also be aligned automatically, the unique phonon bottleneck effect can also shorten the cooling time of hot minority carriers in solar cells, so as to offset the composite barrier effect of traditional silicon-based solar cells. These advantages also make InGaN materials suitable for high efficiency multi-junction solar cell applications in high-end precision equipment [22]. At present, many research institutes and universities are conducting research in the field of InGaN/GaN solar cells [23].Therefore, in this section, InGaN/GaN nanowire solar cells represent the third generation of semiconductor solar cells.

The Physical Science and Technology Research group of Guangxi University recently released a computational paper on the InGaN series of multiple cells, in which the energy conversion efficiency of the three-junction InGaN solar cell reached 41.76% [24].WH Liu et al. studied the effect of ternary mixing and size effect on the optical absorption coefficient of InXGa(1-X)N /GaN CSNW subbands of cylindrical nanowires based on the density matrix method [25].Considering that most InGaN/GaN nanowires grown in practice are prismatic, it is of significance to further explore the influence of the cross section shape on the photoconversion efficiency of InGaN/GaN nanowires. Taking GaN/InGaN materials as an example, MohsenNami et al. finally prepared GaN/InGaN core-shell nanowire with hexagonal cross section by bottom-up growth method[26][27].And then applied it to the design of leds。After testing, its internal quantum efficiency reaches 62%, which can be well applied in the field of solid lighting[28][29].Zhao Qi et al. obtained the optimal combination of InGaN all-solid-state photovoltaic solar cells by adjusting the In component as follows: The In component of the absorption layer is 0.75, and the In component of the barrier layer is 0.58. The photoelectric conversion efficiency of the solar cell under this component is 31.3% [30].Tang Longjuan et al. improved the external quantum efficiency of pGaN/ i-IngAN/n-GaN double heterogeneic junction solar cells by using the nanowire array structure etched P-gan. The experimental results show that the quantum efficiency outside the cell is up to 55%, which also strongly confirms that the nanoarray structure has the effect of improving the absorption rate of ultraviolet light and reducing the light reflection [31].

5. Summary and Prospect

The direction of improving the efficiency of solar cells is generally as follows:

1) The structure and section shape of silicon nanowires were optimized.In 1981, the invention of scanning tunneling microscope was regarded as the beginning of nanotechnology. At present, nanowire is mainly divided into axial heterostructure nanowire and radial heterostructure core-shell nanowire. Nanowires can decouple the direction of light absorption and carrier collection [32], which can effectively improve the charge transport efficiency. The cases of surface passivation, core-shell formation of silicon nanowires, spin-coating of quantum dots and growth of core-shell nanowires with hexagonal cross section are presented.

2) Optimization of silicon nanowire array arrangement and optimization of material surface properties. By changing the length and periodicity of the nanowires, light absorption and light reflection can be improved [18]. For example, Horng et al. designed a mirror structure and used laser emission technology to enhance light absorption in InGaN/GaN thin film cells [33].Examples such as etching and doping of different materials are given.

3) Another important direction to improve the efficiency of the third generation solar cells is to doping other substances. Some organic substances need to be doped by controlling the proportion of alloy composition, so that the band gap width can be continuously changed to improve the solar absorption capacity. This paper presents a solar cell with InGaN/GaN material as an example to obtain the highest efficiency by adjusting the in component.

For the application of silicon solar cells, the main requirements are low price, can be widely used and high efficiency. At present, silicon solar cells can almost meet these requirements, but due to the characteristics of silicon materials, this also leads to its low ultimate efficiency. InGaN/GaN nanowire solar power pursues higher efficiency, which should be more applied to military and high-end equipment while meeting daily application.

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