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Optimization of Surface Material Treatment for High - Performance Solar Panels

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Abstract. This paper delves into the crucial aspects of surface material treatment for solar panels. As the demand for clean and renewable energy sources continues to grow, solar energy has emerged as a promising solution. The efficiency and durability of solar panels are directly influenced by the surface material treatment techniques employed. By exploring various treatment methods, materials, and their impact on performance, this paper aims to provide valuable insights for the development of more efficient and long-lasting solar panels. Firstly, it comprehensively explores a wide array of treatment methods, including chemical etching, plasma treatment, and physical vapor deposition. Each method has its unique characteristics and impacts on the solar panel's performance. Then, delve into various materials utilized in surface treatment, such as anti-reflection coatings like silicon dioxide and protective coatings such as polyvinyl fluoride. It is hoped that these insights will help to develop more efficient solar panels with stronger light absorption capacity and lower reflectance. Moreover, it can also help to create more durable solar panels, so that they can better resist the effects of environmental factors, thereby contributing to the use of solar energy.

Keywords: Solar Panel, Surface Material Treatment, Current Progress, Future Development

1. Introduction

Solar surface material treatment is of multifaceted importance, which can improve the efficiency of photoelectric conversion, enhance durability, improve the overall performance of the system, and meet the aesthetic and installation needs. Moreover, at this stage, the society uses clean energy very extensively, and many aspects of energy conversion are used in solar energy

Solar energy is an almost inexhaustible and inexhaustible clean energy source. Solar panels, also known as photovoltaic (PV) panels, are devices that convert sunlight into electrical energy. The performance of solar panels is determined by a variety of factors, among which surface material treatment plays a basic role. A well-treated surface can enhance light absorption, reduce reflection, and protect the internal components of solar panels from environmental factors.

The basic principle of solar panels is based on the photovoltaic effect, that is, photons from sunlight are absorbed by semiconductor materials to produce electron-hole pairs. These charge carriers are then separated and collected to generate an electric current. However, the presence of surface defects, contaminants, and undesirable optical properties can significantly reduce the

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efficiency of this process. Among many factors, surface material treatment is a key factor in determining the performance of solar panels. The surface of the solar panel is the first contact point with sunlight, and its performance will significantly affect the efficiency of the solar panel in converting light energy. Improperly treated surfaces may have defects and contaminants. The surface is too rough, which may cause more light to scatter in the other direction, thereby reducing the light energy that can be effectively absorbed by the semiconductor. Pollutants such as dust, dirt, or chemical residues will accumulate over time, further reducing the efficiency of the solar panel's conversion of light energy by blocking light or interfering with the transmission of charge carriers.

In addition, the surface material must also be able to withstand the harsh environments that solar panels are usually exposed to. Outdoor solar installations are constantly affected by ultraviolet radiation, temperature differences between day and night, and moisture in the form of rain, moisture, or dew. If the surface material is not properly treated, these environmental factors may cause degradation of semiconductor materials, corrosion of electrical contacts, and damage to the overall structure of the battery panel.

This article describes all aspects of surface material treatment, and wants to more comprehensively explain its importance, treatment methods, materials used, and the impact on the performance of solar panels.

2. Theory

The first is to enhance light absorption. The surface of the solar panel needs to be optimized to maximize the absorption of sunlight over a wide wavelength range. The incident light should be effectively captured and directed into the semiconductor layer. And those surface treatment technologies known at this stage can increase the length of the propagation path of light in the battery panel, thereby increasing the probability of photons being absorbed. For example, the use of nanoscale surface structures can scatter and capture light, thereby achieving more efficient absorption in the near-infrared and visible regions. Secondly, reflection can be reduced. The reflection of sunlight from the surface of the solar panel means a loss of energy. A surface with a high reflectance will cause a large part of the incident light to be reflected back into the atmosphere instead of being absorbed. Anti-reflective coating is a commonly used surface treatment method to minimize reflection. These coatings are formulated with different refractive indices to allow a better transition between the air and the surface of the solar panel, thereby minimizing the reflectance. And prevent environmental degradation. Solar panels are exposed to various environmental factors, such as moisture, temperature changes, and ultraviolet radiation. Proper surface treatment can provide a protective barrier against these factors. For example, hydrophobic coatings can prevent water from attaching to the surface and reduce the risk of corrosion and degradation of internal components. Anti-ultraviolet coatings can absorb or scatter harmful ultraviolet rays and protect semiconductor materials from photodegradation.

3. Advanced surface treatment techniques and their impact on solar panel efficiency

The quality of photovoltaic panels has a decisive impact on the efficiency of photovoltaic power generation. When the materials and processes of photovoltaic panels are determined, the surface defects of photovoltaic panels generated during processing or construction will greatly reduce the reliability and work efficiency of solar photovoltaic power generation systems. Since the surface defects of photovoltaic panels are difficult to directly identify with the naked eye, it is of theoretical and practical significance to study the effective identification of surface defects of photovoltaic

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panels. Through theoretical analysis, software simulation and the construction of an experimental platform, this paper studies the infrared characteristics of typical defects on the surface of photovoltaic panels under different conditions, focusing on the main factors affecting the infrared characteristics of photovoltaic panel defects, namely the influence of ambient temperature. The specific content of the research on infrared detection technology for surface defects of photovoltaic panels includes: First, according to the working principle and parameter model of photovoltaic panels, the influence of surface defects of photovoltaic panels on the internal resistance of photovoltaic panels is theoretically analyzed. The design experiment obtained the internal resistance of normal photovoltaic panels and four common defects of photovoltaic panels with fragment defects, crack defects, broken grid defects and black film defects at an ambient temperature of 25oC, and used the relationship between the internal resistance of photovoltaic panels and the ambient temperature and light radiation intensity to calculate the internal resistance of photovoltaic panels at 30oC and 35oC to determine the influence of ambient temperature on the internal resistance of photovoltaic panels. Secondly, a simulation model of the temperature field of typical defects on the surface of photovoltaic panels is established under the ANSYS simulation software environment. The equivalent substitution method is used to simulate the four common defects of photovoltaic panels, and infrared images of different defects of photovoltaic panels are obtained. On this basis, the typical infrared characteristics of fragments, cracks, broken grids, and black film defects are theoretically analyzed. Subsequently, through the selection of devices, the design of simulated lighting schemes, and the calculation and analysis of light uniformity, the experimental platform for infrared detection of surface defects of photovoltaic panels was completed. Then, at an ambient temperature of 25 °C, 30 °C, and 35 °C, the infrared imager was used to obtain infrared images of the surface of normal photovoltaic panels and the four common defects of photovoltaic panels: fragment defects, crack defects, broken grid defects, and black film defects. The image processing method is used to determine the types of defects of the four common defects of photovoltaic panels. In this topic, the infrared characteristics of surface defects of photovoltaic panels are analyzed through theory and simulation, and the infrared characteristics of surface defects of photovoltaic panels are verified through experimental analysis. The results show that it is effective and feasible to realize the surface defects of photovoltaic panels through infrared detection technology [1].

The surface of the antimony selenide thin film layer in the antimony selenide thin film solar cells was treated by liquid contact containing carbon disulfide, and the surface of the treated antimony selenide thin film layer was used as the back surface of the antimony selenide thin film solar cells. The present invention improves the back surface of the antimony selenide thin film layer in the antimony selenide thin film solar cell, effectively reduces the back contact barrier of the antimony selenide thin film solar cell, achieves the effect of increasing the fill factor of the device, and then improves the photoelectric conversion efficiency of the antimony selenide thin film solar cell [2].

In the solar cell manufacturing industry, to solve the problems of high chemical consumption and large amounts of silicon wafer removal in the traditional surface treatment before silicon wafer texturing, the electrochemical cleaning method is introduced. This method uses the strong oxidation properties of special reagents after electrolysis, and effectively cleans the organic matter on the surface of the silicon wafer through the combination of corrosion, oxidation and cleaning, and the amount of silicon wafer removal is small. It can be seen from the experiment that the removal amount is reduced by 1/2. By applying the diamond membrane electrode, the special reagent electrolyte can be efficiently produced. XPS showed that electrochemical cleaning could effectively remove organic pollution. The results of silicon wafer texturing after electrochemical cleaning and RCA cleaning were compared, and it was proved that the texturing effect of electrochemical

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cleaning was good. The electrolyte can still be effectively reused after electrode treatment, indicating that electrochemical cleaning can effectively control emissions and is an effective method for removing organic matter in large-scale industrial production [3].

The mechanism mainly involves the use of hydrogen plasma bombardment, which bombards the surface of the junction in the tandem thin-film solar cells, creating additional defects at this junction. These defects increase the probability of electron-hole recombination, effectively preventing carrier separation and forming a reverse built-in electric field, resulting in a good tunnelling junction for the tandem thin-film solar cells. If the second layer of the thin-film solar cell is crystalline, the defects at this junction also help to improve the quality of thin film deposition crystallisation, significantly enhancing the efficiency of the thin-film solar cells [4].

4. Now known surface material treatment technology

The surface modification of the back film material of solar panels was carried out with atmospheric pressure and low temperature plasma generated by air-mediated barrier discharge (DBD). The changes in surface hydrophilicity and surface energy of the back film before and after DBD modification were measured by a contact angle measuring instrument, and the physical structure and chemical composition of the back film before and after modification were analyzed by scanning electron microscope (SEM) and total reflection Fourier infrared spectrometer (ATR-FTIR). The changes in the surface structure and chemical composition of the back film before and after the modification, and the degradation effect of the treated material and the influence of power density were studied. The contact angle measurement results show that after DBD plasma treatment, the surface energy of the back film material is improved, the hydrophilicity is enhanced, and the contact angle and surface energy both reach the saturation value within a certain treatment time; SEM observation found that the roughness of the surface of the back film after treatment increased; FTIR analysis showed that the chemical groups on the surface of the back film after treatment changed, and oxygen-containing polar groups were introduced. When the treated material is placed in the air, the degradation effect will occur, but even after 6 d, the water contact angle on the surface of the material is still much lower than the value before the treatment. Increase the power density of DBD processing, and the same processing effect can be obtained with less processing time [5].

The photoelectric conversion efficiency of organic-inorganic hybrid perovskite solar cells has achieved rapid development in recent years, but stability is a factor restricting their commercial application. Fully inorganic perovskite CsPbX3(X=Cl, Br,I) solar cells have aroused widespread interest among researchers because of their excellent light and thermal stability, but due to the rapid crystallization process of fully inorganic perovskite thin films, the film quality is too poor and the density of large defect states is one of the reasons that restrict the further improvement of the efficiency of fully inorganic perovskite solar cells. In view of the above problems, in this paper, use different concentrations of ammonium metavanadate (NH4 VO3) solution to perform droplet treatment of perovskite films, and perform secondary annealing to promote the secondary growth of perovskite grains. The study found that the film treated with NHVO3 solution with a concentration of 2.5 mg/mL is denser, has a larger grain size, and has a higher electron/hole migration capacity. The corresponding device obtained a photoelectric conversion efficiency of 15.45% under the standard sunlight of AM 1.5G, which is much higher than the efficiency of 12.19% of untreated thin film devices. This work provides a simple and effective method for realizing efficient and stable fully inorganic perovskite solar cells [6].

The utility model discloses a surface treatment device for a photovoltaic solar cell, which comprises a bottom plate, a control panel, a first vertical plate, a second vertical plate and a nozzle.

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The top side of the bottom plate is fixed with a first vertical plate, and the inner wall of the first vertical plate is provided with a liquid storage tank, and the liquid storage tank is away from the first vertical plate. The side of the bottom plate is provided with a treatment box, the outer wall of the treatment box away from the first vertical plate is provided with a second vertical plate, the bottom end of the second vertical plate is fixedly connected with the top of the base plate, and one end of the treatment box is provided with a nozzle, the liquid storage tank A high-pressure pump is installed at the top of the bottom plate below, and a second infusion tube is installed at one end of the high-pressure pump, and a first solenoid valve is installed on the outer wall of one side of the second infusion tube. The utility model not only improves the processing effect of the processing device when it is used, but also improves the processing efficiency of the processing device when it is used, and also improves the energy saving of the processing device when it is used [7].

The invention discloses a surface treatment method of a TCO conductive material on a solar cell. The specific steps include: contacting the TCO layer with a conductive solution containing a lower concentration of acid, and providing electrons to the surface of the TCO, forming a current at the interface between the TCO and the conductive solution, the direction of the current flows from the conductive solution through the interface between the TCO and the solution, and connecting to the electrode in the conductive solution to form a conductive circuit. Through the above method, the present invention relates to a surface treatment method of a TCO conductive material on a solar cell. The method can improve the adsorption force between the coating and the TCO surface by treating the TCO surface before electroplating, so that sufficient adsorption force is achieved when the metal is directly electroplated on the TCO [8].

The invention belongs to the technical field of dye-sensitized solar cells, in particular to a dual-surface treatment method for improving the photoelectric conversion efficiency of barium stannate-based dye-sensitized solar cells. The invention uses a water bath method to prepare pure-phase BaSnO nano-particles, which are applied to the photoanodes of dye-sensitized solar cells. Subsequently, the BaSnO nano-particle photoanodic film was surface treated by chemical bath deposition method (CBD) and TiCl solution soaking method. The dye-sensitized solar cell assembled with ruthenium dye N719 as the sensitizer was used. At a light intensity of 100mW/cm, under the condition of AM1.5, its highest photoelectric conversion efficiency is 5.18%; This method is simple to operate and low in cost, but it greatly improves efficiency and has high practicality [9, 10].

Durability and long-term stability are also inseparable from surface treatment. Solar panels are exposed to complex natural environments for a long time and face many challenges. The protective coating is like installing a protective cover on the battery panel, which effectively prevents environmental degradation and ensures that the performance of the battery panel remains stable over time. The hydrophobic coating can cleverly prevent water from entering, avoiding water corrosion of electrical contacts and damage to semiconductor materials. For example, in the rainy season, a lot of rain falls on the battery panel. If there is no hydrophobic coating, water may penetrate into the interior of the battery panel, causing serious problems such as short circuits. With this coating, water cannot be attached, greatly reducing the risk of failure. The anti-ultraviolet coating is like a protective umbrella, protecting the solar panel from the harmful effects of long-term ultraviolet exposure, allowing the material to maintain good performance for a long time, prolonging the service life of the solar panel and reducing costs.

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5. Conclusion

Surface material treatment occupies an important position in the field of solar panel technology, which has a great impact on its efficiency, durability and long-term performance.

In terms of efficiency improvement, the effect of surface treatment is extremely outstanding. By reducing reflection and enhancing light absorption, more photons can be converted into electrical energy, which has a direct effect on the power generation capacity of solar panels. Taking the anti-reflective coating as an example, its exquisite design can increase the short-circuit current density (Jsc) of solar panels. When light hits the surface of the battery panel, the anti-reflective coating is like a precision optical regulator, introducing more light that might have been reflected back into the interior of the battery panel, causing more photons to participate in the photoelectric conversion process. The texturing of the surface also has a significant effect. By increasing the interaction between light and matter, the internal quantum efficiency (IQE) of the solar panel is improved. Related studies have shown that optimized surface treatment can increase the overall conversion efficiency of solar panels by several percentage points. Don't underestimate these percentage points. In large-scale applications, this means a significant increase in the total amount of power generation, which can provide sufficient clean energy for more regions and help optimize the transformation of the energy structure.

However, surface material treatment also faces many challenges. Cost-effectiveness is a major problem that needs to be solved urgently. Although some advanced processing methods and high-performance materials have significant effects, they are relatively expensive, which undoubtedly greatly increases the overall production cost of solar panels. For example, some high-performance anti-reflective coating materials have high prices due to their difficult research and development and complex production processes, which puts solar energy at a disadvantage in the cost competition with traditional energy sources. The development of more cost-effective processing technologies and materials has become the key to promoting the widespread application of solar energy.

In the present and in the future, the research on the surface material treatment of solar panels has broad prospects. The development of new materials and processing technologies will become the key direction. Exploring the use of nanocomposites for anti-reflective and protective coatings is expected to bring better performance breakthroughs. Self-cleaning and self-repairing surface treatment technologies also have great potential. They can further improve the durability and maintenance-free operation capabilities of solar panels and reduce labor maintenance costs. In addition, combining surface treatment with new solar cell architectures (such as perovskite solar cells) also provides new ideas for optimizing performance.

In short, surface material treatment is one of the core elements of solar panel technology development. Despite the current challenges, as long as it continues to innovate and actively respond, the performance and competitiveness of solar panels will be significantly improved in the future, making a huge contribution to the global clean energy transformation and helping mankind move towards a sustainable energy future.

References

[1] Tao, W. (2025) Research on infrared detection technology for surface defects of photovoltaic panels. Doctoral dissertation, China Jiliang University.

[2] Tang, J., Zhao, Y., Niu, G., Wang, L., Li, D., & Chen, C. et al. (2017) A back surface treatment method for antimony selenide thin-film solar cells. CN106920863A.

[3] Wang, Z., Liu, Y., & Zhang, J. (2009) Application of electrochemical cleaning before texturing in solar cells. Micro Nanoelectron. Technol. 46(2), 119–122.

DOI: 10.54254/2755-2721/2026.MH30257

[4] Jian, W., Liu, Y., & Liu, J. (2013) Surface treatment technology of double-junction thin-film solar cell interfaces. CN103022223A.
[5] Fang, Z., Yang, H., Si, Q., Zheng, X., & Xie, X. (2010) Improving surface energy of solar cell backsheet by dielectric barrier discharge treatment. High Volt. Eng. 36(2), 417–422.
[6] Li, X., Wang, D., & Lou, Y. (2020) Surface treatment improves the performance of all-inorganic CsPbBrI2 perovskite solar cells. Battery Ind.
[7] Liu, Y., & Zhang, Z. (2022) A surface treatment device for photovoltaic solar cells. CN215600385U.
[8] Shi, J., Meng, F., Han, A., Zhang, L., Liu, Z., & Xie, Y. (2022) A TCO thin-film surface treatment method for SHJ solar cells. CN202010566394.2.
[9] Wei, M., Xie, F., & Li, Y. (2019) A dual surface treatment method for improving the photoelectric conversion efficiency of barium stannate-based dye-sensitized solar cells. CN201710894076.7.
[10] Chen, Y., Jiang, D., Zeng, T., Shi, Y., Tang, Q., & Dong, G. et al. (2025) A nano barium stannate-based powder, its preparation method, and applications