Preparation of SiO_2 Aerogel for Solar Energy and its Application

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Abstract

SiO_2 aerogel, as a new type of material with the properties of porous, low density and high specific surface area, has attracted much attention in several fields in recent years. Its excellent thermal, optical and mechanical properties make it a great potential for application in solar energy. In this paper, the preparation process of SiO_2 aerogel is reviewed, including the main steps and key technologies of sol-gel method. Meanwhile, the applications of SiO_2 aerogels in solar collectors, transparent insulation materials and solar cell modules are discussed in detail, as well as their advantages in improving solar energy utilisation and performance. In addition, this paper also looks forward to the future development trend and prospect of SiO_2 aerogel in solar energy, which provides useful references and insights for related research and applications.

Keywords

SiO_2 Aerogel; High Specific; Low Density.

1. Introduction

With the increasing demand for energy by human beings and the growing awareness of environmental protection, solar energy, as a clean and renewable form of energy, has received more and more attention and research.SiO_2 aerogel, as a new type of porous, low-density, high specific surface area material with excellent thermal, optical and mechanical properties, has a promising prospect for its application in the field of solar energy.

Since the Industrial Revolution, fossil energy sources have greatly satisfied mankind's need for energy, but at the same time they have brought about negative impacts such as environmental pollution and the greenhouse effect, and continue to threaten the subsequent survival and development of human society. China is a large energy-consuming country, and according to the National Bureau of Statistics, China's annual energy consumption in 2020 will be 4.98 billion tonnes of standard coal, with coal-based fossil energy accounting for 84.1% of the total energy consumption. In order to achieve China's "carbon peak, carbon neutral" strategic goal, it is necessary to change the original energy supply mode, promote the transformation of China's energy supply system, and China's rich endowment of renewable energy resources is to achieve the basis of low-carbon energy transformation. Among the many renewable energy sources, solar energy is one of the most abundant green energy sources in China, especially in the vast areas in the west of China; its effective use can help to reduce environmental pollution and the adverse effects of the greenhouse effect. The State Council's "Carbon Peak Action Programme by 2030" clearly proposes that by 2030 China's total installed capacity of wind and solar power generation should reach more than 1.2 billion kilowatts[1]. At present, solar power generation mainly consists of photovoltaic power generation and solar thermal power generation, while solar thermal power generation has very low carbon emissions in the whole life cycle and can provide a more stable power output compared with other renewable energy sources, which is a power generation method with broad prospects for development[2]. The United States is

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the earliest country in the world to operate a solar thermal power plant, operating the first commercial solar thermal power plant as early as 1985[3]. In China, since the construction of the first batch of solar thermal power generation demonstration projects in 2016, several solar thermal power stations have been built and put into operation in the western region of China[4]. In addition to this, a number of recent wind-solar-thermal complementary development projects have also entered the development stage, in which solar thermal power generation technology is used to regulate the system power output, and the implementation of these projects will promote the rapid development of the solar thermal power generation field in China. There are four main types of solar thermal power generation systems: trough, tower, disc and linear Fresnel. High-temperature photothermal conversion of solar energy is the energy conversion process that solar thermal power generation systems must undergo to utilise solar energy. The next-generation concentrating solar photovoltaic power generation technology route released by the U.S. National Renewable Energy Laboratory (NREL) requires that the collector temperature of solar concentrating collector power generation should reach above 700°C in order to improve the power generation efficiency of the subsequent power cycle[5]. And at high temperatures, how to effectively suppress the solar receiver's photothermal loss and improve its photothermal conversion efficiency is the key to improve the energy efficiency of the whole system[6]. Transparent SiO_2 aerogel, as a kind of nanoporous material, has excellent properties such as low thermal conductivity, low refractive index, and high transmittance to solar radiation, which makes it a transparent thermal insulation material with excellent performance[7]. When sunlight is incident on the surface of transparent SiO_2 aerogel, the low refractive index of transparent SiO_2 can reduce the reflection loss of sunlight. Highly transparent SiO_2 aerogel has a high transmittance to solar radiation on the one hand, allowing solar radiation to pass through, while on the other hand, it has a certain absorption effect on infrared heat loss, which enhances the absorption of infrared heat radiation and reduces radiant heat loss. In addition, the special three-dimensional structure of transparent SiO_2 aerogel makes it have a low thermal conductivity also plays a role in suppressing heat loss. These properties make transparent SiO_2 aerogels have a broad application prospect in the fields of building energy saving and solar thermal conversion [8,9].

2. Introduction of Materials

SiO_2 aerogel is a new type of porous low-density nanomaterials with large specific surface area, continuous three-dimensional network structure, and can be modified and controlled at the nanoscale, etc. It exhibits distinctive optical, thermal, mechanical, and electrical properties, and has a broad and attractive application prospect.The pore size, pore size, and particle size are about tens of nanometers, and it is the smallest apparent density condensed material in the world today. SiO_2 aerogel is one of the solid materials with the lowest thermal conductivity and excellent visible light transmittance, which makes it an excellent transparent thermal insulation material. Transparent SiO_2 aerogel has strong Rayleigh scattering for blue and violet light, so the samples often show a light blue colour. the relationship between the refractive index of SiO_2 aerogel and its density is: $n-1 \approx 2.1\times10^{-4}\rho$, where ρ is in kg-m^{-3}, from which it can be seen that the refractive index of the aerogel is very small, so SiO_2 aerogel has a better transmittance than other materials. has better transmittance than other materials.

2.1 SiO_2 Aerogel in Solar Energy Applications

There are four main types of solar photovoltaic power generation systems: trough, tower, dish, and linear Fresnel. The high-temperature photothermal conversion of solar energy is the energy conversion process that solar thermal power generation systems must undergo to utilise solar energy. The U.S. National Renewable Energy Laboratory (NREL) released the next generation of concentrating solar photovoltaic power generation technology route requires solar concentrating collector power generation collector temperature to reach 700°C or more in order to improve the subsequent power cycle power generation efficiency. And at high temperatures, how to effectively inhibit the solar receiver's photothermal loss and improve its photothermal conversion efficiency is

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the key to improve the energy efficiency of the entire system. Transparent SiO_2 aerogel, as a kind of nanoporous material, has excellent characteristics such as low thermal conductivity, low refractive index and high transmittance to solar radiation, which makes it a transparent thermal insulation material with excellent performance. When sunlight is incident on the surface of transparent SiO_2 aerogel, the low refractive index of transparent SiO_2 can reduce the reflection loss of sunlight. Highly transparent SiO_2 aerogel has high transmittance to solar radiation on one hand, allowing solar radiation to pass through, while on the other hand, it has a certain absorption effect on infrared heat loss, which can enhance the absorption of infrared heat radiation and reduce the radiant heat loss. In addition, the special three-dimensional structure of transparent SiO_2 aerogel makes it have low thermal conductivity and also plays a role in suppressing heat loss. These characteristics make transparent SiO_2 aerogels have a broad application prospect in the fields of building energy saving and solar thermal conversion.

2.2 SiO_2 Aerogel in the Field of Heat Insulation and Thermal Insulation Material Applications

Aerogel is a highly dispersed solid material consisting of colloidal particles or inorganic SiO_2 polymer molecules aggregated with each other in a nanoporous network structure and filled with gaseous dispersed medium in the pores, which is currently the most excellent performance of the thermal insulation materials.The excellent thermal insulation performance of SiO_2 aerogel is determined by its structure. For nanoporous thermal insulation materials, the thermal insulation performance is mainly determined by the performance of solid heat conduction, gas heat conduction and radiation heat conduction. Solid physics research shows that solid phase heat transfer is related to the density and porosity of the aerogel. The principle of solid state physics: under the condition of ensuring the usual good mechanical properties of aerogel, reducing the density and increasing the porosity of aerogel can reduce the solid-phase heat conduction within a certain range. The chemical bonds between SiO_2 nanoparticles combine with each other into very long helical hinges, which greatly reduces the density of the material, increases the porosity of the material, and grows the solid-phase heat conduction paths, thus reducing the solid-phase thermal conductivity.

Studies have shown that the gas heat conduction of solid materials is mainly related to the structure of the micropores that make up the material, and the pore size distribution, pore size and pore volume determine the microporous structure. In the case of SiO_2 aerogel insulation materials, gas heat conduction can be effectively reduced because 80% of the pores in its structure are smaller than 50 nm. However, it should be noted that when the density of the material is less than 0.1 g/cm^3, it leads to a significant increase in the pore size of the aerogel. Therefore, in order to inhibit the increase of gaseous heat transfer in aerogel materials, it is necessary to control the size of the aerogel pore size in the nanoscale range, and control the density range from 0.10 to 0.15 g/cm^3.

Studies have shown that at high temperatures, the radiative heat conduction of SiO_2 aerogel thermal insulation materials leads to greater thermal conductivity. High-temperature thermal radiation is mostly an infrared radiation phenomenon, and various shading agents need to be added to the material when it is used at high temperatures. Commonly used shading agents include carbon black, potassium hexatitanate whiskers, $ZrSiO_4$, TiO_2 and SiC. The size of the opacifier particles is approximately an integral multiple of the common infrared wavelengths. When heat passes through the aerogel in the form of infrared radiation, it will be absorbed, reflected and scattered by the shading agent, thus achieving the purpose of thermal insulation. In conclusion, the structural characteristics of SiO_2 aerogel make the material have excellent thermal properties of solid heat conduction, gas heat conduction and heat radiation, making it an excellent thermal insulation material.

2.3 SiO_2 Aerogel in the Field of Energy Storage Material Applications

SiO_2 aerogels can be used as excellent energy storage materials due to their high specific surface area and porous structure.SiO_2 aerogels can be used as electrode materials for supercapacitors for storing and releasing electrical energy. In addition, SiO_2 aerogel can be used as electrolyte filler or electrode material for lithium-ion batteries to improve the energy density and cycle life of the batteries.

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Lithium battery system requirements for thermal insulation materials is excellent thermal insulation performance at the same time need to have excellent flame retardant properties, conventional insulation materials polyurethane due to the ambient temperature of more than 140 degrees Celsius easy to burn, so it is not suitable for lithium batteries as a flame retardant material. In addition, out of the pursuit of volumetric energy density, lithium battery manufacturers in the Pack design of the space reserved for the thermal insulation layer between the battery core is not large, aerogel with good flame retardant properties and low dosage characteristics, lithium battery battery core thermal insulation material has become the best choice. According to the patents of Ningde Times and SAIC Group, the mainstream thermal insulation solution is to place aerogel inserts between the cores, and to set mica sheets between the module and the top cover.

There are many types of aerogel materials, among which SiO_2 aerogel has the most mature commercial application. Aerogels can be classified into seven categories according to precursors: oxides, carbons, polymers, biomass, semiconductors, non-oxides, and metals. Many different precursors can be prepared with different properties of the aerogel, greatly enriching the diversity of aerogel varieties and expanding the scope of aerogel applications. The application of SiO_2 aerogel is the most mature in the current market, and the global silica aerogel accounted for 69% in 2019.

2.4 SiO_2 Aerogel in Catalyst Carrier Application

SiO_2 aerogels are highly dispersible and chemically stable, and are suitable as catalyst carriers. By loading the catalyst onto SiO_2 aerogels, the activity, stability and selectivity of the catalyst can be increased, and the efficiency of the catalytic reaction and the purity of the product can be improved. SiO_2 aerogels have a wide range of applications in catalytic cracking, catalytic hydrogenation, catalytic oxidation and other reactions.

Using the high specific surface area, high porosity and nanopore structure of Si0,aerogel, it was used as a catalyst carrier for the synthesis of diphenyl carbonate (DPC), an important chemical product, from phenol, C0 and O,to improve the synthesis efficiency. The Si0, aerogels were prepared by atmospheric pressure drying using sol-gel method with water glass as the silica source, formamide as the catalyst and ethylene glycol as the drying control chemical additive (DCCA). Cw/Si0,composite aerogel catalysts and carriers containing Cu additives can be obtained by mixing copper salt solutions with silicon sources and other sources by sol-gel process. The microstructure, morphology and properties of the aerogels were investigated using Fourier transform infrared analysis, thermogravimetric analysis, differential scanning calorimetry analysis, specific surface area determination (B.E.T.) as well as scanning electron microscopy and transmission electron microscopy. The experimental results show that:the preparation process of Si0,aerogel has a large influence on its microstructure and mechanical strength, and the appropriate excess of formamide can increase the porosity and catalyst loading of Si0,aerogel:the heat treatment at the appropriate temperature can significantly improve the mechanical strength of the material without significantly reducing the specific surface area of the material. The produced Si0,aerogels and Cu/Si0,composite aerogels as carriers, after loading catalyst PdCl, and copper salt additives, showed high catalytic activity and obtained ideal yields of diphenyl carbonate at 100°C and 3.7 MPa.

2.5 SiO_2 Aerogel Transparent Insulation Material

As modern building and energy technologies continue to advance, there is a growing demand for transparent insulation materials. As a new type of porous material, SiO_2 aerogel shows a broad application prospect in the field of transparent thermal insulation materials with its unique structure and properties, such as high light transmittance, low refractive index and extremely low thermal conductivity, making it an ideal transparent thermal insulation material. SiO_2 aerogel has high light transmittance, low refractive index, and very low thermal conductivity, which make it an ideal transparent thermal insulation material. Its high transmittance ensures that light can pass through smoothly and maintains good visual permeability, while its low refractive index reduces the reflection and scattering of light inside the material, further improving the light transmission rate. In addition, the low thermal conductivity of SiO_2 aerogel means that it can effectively block heat transfer and

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reduce energy loss.SiO_2 aerogel transparent insulation has significant advantages over traditional insulation materials. Firstly, its high light transmission and low refractive index ensure a good visual effect without affecting the appearance and use of the building. Secondly, the low thermal conductivity of SiO_2 aerogel can effectively reduce heat transfer and dissipation and improve the efficiency of energy utilisation. In addition, SiO_2 aerogel has excellent chemical stability and durability, and can maintain stable performance under various environmental conditions.

Currently, SiO_2 aerogel transparent thermal insulation materials have been widely used in building windows, greenhouses, automobile windscreen and other fields. Through the verification of actual application cases, SiO_2 aerogel transparent thermal insulation material significantly reduces heat transfer and dissipation while maintaining good visual effects, improving the comfort of the indoor environment and the efficiency of energy use.

In the future, with the continuous improvement of SiO_2 aerogel preparation technology and the expansion of application fields, its application in the field of transparent thermal insulation materials will be more extensive. Meanwhile, researchers will further explore the composite technology of SiO_2 aerogel with other materials to prepare transparent thermal insulation composites with more excellent performance to meet the needs of different fields.

3. Preparation of SiO_2 Aerogel

In general, there are many ways to prepare SiO_2 aerogels, but the main common ones are the acid-catalysed method, the base-catalysed method, and the acid-base-catalysed sol-gel method. The most commonly used method is the acid-base catalysed sol-gel two-step method. And the process of preparing SiO_2 aerogel by acid-base catalysed sol-gel two-step method is mainly divided into three parts: (1)Preparation of raw materials. (2) Preparation of gel: SiO_2 silica gel is obtained by sol-gel method. The prepared sol contains the silica source solution as well as the catalyst, and then the sol is only gelated. Gels can be divided into hydrogels, alcohol gels, and aerogels (the dispersing media are water, ethanol, and air, respectively) according to the dispersing media used. (3) Aging of wet gel: the gel obtained in the first step is aged in the mother liquor. The aging process is to further promote the sol into a gel, which can make the drying process of the gel shrinkage to a minimum. (4) Drying of the wet gel: In this step, the gel must be free from the liquid in the micropores. Drying must be carried out under special conditions to prevent the collapse of the gel structure.

(1) Preparation of raw materials

Choose high-purity silicon sources (such as sodium silicate, ethyl silicate, etc.) as starting materials, and prepare appropriate amounts of catalysts (such as acid, alkali, etc.) and additives (such as surfactants, stabilisers, etc.).

(2) Preparation of wet gel

In the acid-base catalysed sol-gel two-step process, ethyl orthosilicate (TEOS) is used as the silicon source, and anhydrous ethanol is used as the solvent to prepare SiO_2 wet gels. The process is divided into three steps: the first step is the hydrolysis of TEOS under acidic conditions to form silicic acid and the corresponding alcohols; the second step is the condensation reaction between silicic acid or between silicic acid and TEOS under alkaline conditions, after which it becomes a colloidal polymer; the third step is the low polymer that has been formed in the reaction to continue to polycondense to further form a three-dimensional network-like structure, the specific reaction process is as follows:

The first step is the hydrolysis reaction of TEOS, which is the gradual substitution of the -OH group on the water for the $-OC_2H_5$ on its silicon bond.

The second step: Si-O-Si is formed by further dehydration and condensation between Si-OH and $-OC_2H_5$ of silicic acid, and Si-O-Si is formed by alcohol loss condensation between Si-OH and $-OC_2H_5$ of silicic acid, and after the above reaction, there are still some silicon atoms with -OH, and through the condensation reaction between the groups, the primary particles with the structure of $[SiO_4]$ tetrahedra will be generated, and each $[SiO_4]$ tetrahedral structure is formed. The four vertices of each

[SiO_4] can be connected with the surrounding [SiO_4], constituting a three-dimensional network structure, that is, the generation of secondary colloidal particles, so that the system from a solution to a sol.

The third step: sol to gel transformation process, Si-O-Si further condensation between the polymerisation reaction process of the sol-gel process consists of the following three stages:(1) the solution phase of the monomers through polymerisation to form sol particles; (2) particles grow up, aggregated to form small clusters; (3) small clusters occur mutual cross-linking to form large clusters and throughout the entire liquid medium, the network coarsens to form a gel. Thus the wet gel is obtained.

(3) Aging of wet gel

The skeleton strength of the initially formed gel is relatively low, and the skeleton strength of the gel can be further improved by the aging process. In short, the aging process is equivalent to the continuation of gelation, after the formation of the gel, the solution phase of the monomer or smaller gel clusters continue to polymerisation and through the network connection, and at the same time the gel network has been formed between each other will occur cross-linking, the network gradually become thicker, and the gel strength is also improved. During the aging process, the silica gel also undergoes a partial dissolution-recondensation reaction, while the network becomes smooth due to the presence of surface energy. As the void network of the wet gel is filled with the residual liquid solvent after the reaction, the gel aging process is usually anhydrous ethanol as a replacement solvent to replace, so as to remove the water in the gel to achieve the subsequent drying requirements, and then through the drying process will be the liquid reagent between the void network evaporation, but also to try to maintain the original network skeleton structure of the gel, so that it will be obtained in the pore filled with air in the SiO_2 aerogel with air-filled pores.

(4) Drying of wet gels

After the sol-gel and aging process and the wet gel, which is mainly composed of elastic three-dimensional network skeleton structure, and these network structure of small holes filled with liquid medium. In order to obtain SiO_2 aerogel, traditionally, supercritical drying method is often used to prepare aerogel, the working principle is to make the drying medium reach the supercritical state through high temperature and high pressure, at this time the gas-liquid interface disappears, and forms a kind of homogeneous fluid bounded between the gas and the liquid, and at this time, the surface tension no longer exists, which avoids the shrinkage of the gel and the collapse of the porous network structure, so that the nanopores with complete structure and good performance can be obtained. nanoporous SiO_2 aerogel with complete structure and good performance. The drying medium generally exists in three states of solid-liquid-gas, and when its state is above the critical temperature and critical pressure, it is presented as a supercritical state, and when the temperature in the system is close to the critical temperature, the interface between gas-liquid disappears. As the pressure of the whole system in the supercritical state is very high, the solvent in the system will expand but not boil, and it will become a single-phase fluid with properties between liquid and gas. With the disappearance of the gas-liquid interface, the interfacial tension in the pores of the sample no longer exists, thus avoiding the destruction of the gel structure during the drying process and protecting the original nanoporous structure of the gel, thus obtaining aerogels with a high specific surface area.

4. Conclusion

The trend of mass data in power system provides a basis for load characteristic analysis and prediction model establishment, but the classical load forecasting method can not afford such a huge time and computing resource consumption. The problem of over fitting in large sample set will affect the prediction accuracy. In this paper, a power load forecasting model is built by using the BP neural network model, making full use of the powerful data processing function of Clementine and preventing the over fitting function. The experimental results show that the BP neural network model has good predictability and robustness, and has a certain practical application value.

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