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Preparation of two-dimensional assembled silver nanowires and the disturbances faced

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Abstract. At present, self-assembled materials are widely applied and have become one of the most important methods for the preparation of nanomaterials due to their scale effect and structural diversity. Nanoscale self-assembled materials can be used to prepare media with different pore sizes, morphologies and distributions, resulting in larger specific surface area and transparency. Moreover, they can be used to prepare nanoelectronic devices, nanosensors, and nanophotonic devices. Metal self-assembled materials are widely used in nanocatalytic reactions, where their high specific surface area can improve the reaction efficiency and catalytic activity. Silver nanowires, a branch of self-assembled material, are excellent materials for fabricating transparent flexible electrodes. However, the preparation process of silver nanowires faces many difficulties, and it is very challenging to make the final product with low resistivity. Therefore, the paper aims to explore the preparation of silver nanowires and the many interfering factors facing the preparation process. Through the review of related literature, this paper analyzes the basic principles of a series of self-assembled materials, improves further understanding of the concept and application of self-assembled materials, and thus indicates the preparation methods that can obtain silver nanowires with better performance.

Keywords: Silver Nanowires, Self Assembly Technology, Two-Dimensional Assemblies, Thermal Stability, Polymer Film

1. Introduction

In the context of the expansive self-assembly market, two-dimensional components exhibit considerable application potential and market viability. They have demonstrated exceptional performance in a range of fields, including smart sensors, display devices, flexible electrodes, and others. The scope of application for silver nanowires is also expanding, with continued growth projected at a high rate. Nevertheless, numerous challenges and limitations persist in the preparation process, deviating from the ideal state. One such challenge is the difficulty in achieving high transparency and low resistivity of the prepared silver nanowires, which presents a significant obstacle. The urgent challenge at present is to identify a solution that reconciles the conflicting requirements of high transparency and low resistivity in silver nanowires. On this basis, the paper thoroughly delves into the preparation of two-dimensional assemblies nanowires and the disturbing factors facing the preparation process. By investigating different preparation processes and material selection, it aims to improve the performance and stability of the nanowires, thus providing solutions to the difficulties encountered at this stage and promoting

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their application in various fields. Therefore, this paper summarizes the progress of current research and proposes some novel solutions and technological paths for future research.

2. Overview of the Self-Assembly Technology

2.1. Basic Concepts of Self-Assembly Technology

The transition of particles from a dispersed state to a condensed state is called the initial stage of self-assembly, followed by the gradual formation of self-assembled bodies with stable ordered structures under various intermolecular forces. The assembly mechanism involved in the self-assembly process determines the interaction mode between the final formed components, as well as their structure and properties. The self-assembly mechanism has always been a hot topic in the field of nano self-assembly research. The interaction forces between nano self-assembled materials mainly include van der Waals forces, electrostatic forces, hydrogen bonding, magnetic interactions, entropy driven interactions, and hydrophobic solvent interactions between components A series of ways of action, such as DNA directing [1].

2.2. Basic Definition of Two-Dimensional Self-Assemblies

The self-assembly technology assembles ordered structures through a series of forces, exhibiting high performance and versatility, as shown in Figure 1. The process of self-assembly is not simply the superposition of interactions between a large number of atoms, ions, and molecules, as people think. It is a whole formed by the synergistic effect between individuals. The biggest advantage of two-dimensional self-assembly is that the spontaneous self-assembly process allows for multi-scale installation, resulting in lower defect levels in the final assembly and the ability to assemble each component according to the optimal structure and method [2].

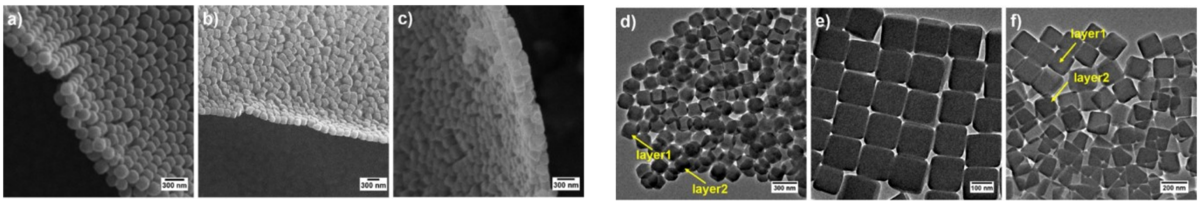

Figure 1. Image of Two-Dimensional Self-Assemblies

3. Properties and Preparation of Two-Dimensionally Assembled Silver Nanowires

3.1. Basic Properties of Silver Nanowires as Transparent Flexible Electrodes

Silver nanowires are a transparent, flexible electrode with exceptional resistance to bending, electrical conductivity, and transparency. Stretchable electrical interconnects and flexible electronic components are two examples of silver nanowire flexible electronic systems. In electronics applications, silver nanowires offer excellent electrical conductivity, transparency, and flexibility. In order to advance the development of flexible systems at the system level (such as intelligent robots, touchscreens, etc.), it will be essential to enhance and advance the techniques for preparing transparent silver nanowire electrodes. Additionally, the inherent low resistivity and high transparency of these electrodes must be overcome. When utilized as transparent, flexible electrodes, the fundamental characteristics of silver nanowires fall into the following categories.

3.1.1. Conductivity and Thermal Conductivity. Silver has the highest electrical and thermal conductivity of any metal, and silver powders have a wide range of applications in thermal interface materials for conductive fillers and conductive binders. For example, the theoretical percolation threshold for randomly dispersed one-dimensional (1D) elongated particles with an aspect ratio of 1000 is 0.05 Vol.%, while the threshold increases to 16 Vol.% for spherical particles. Under two-dimensional (2D) conditions, silver nanowires can also be used as highly conductive percolation paths and conductive electrodes in random networks such as glass, plastic sheets and other materials [4]. It is due to its uniquely low percolation threshold that it is characterized by a large conductive area.

3.1.2. High Transparency. The high transparency of silver nanowires is determined to some extent by the extremely fine diameter of the silver nanowires themselves, as shown in Figure 2.

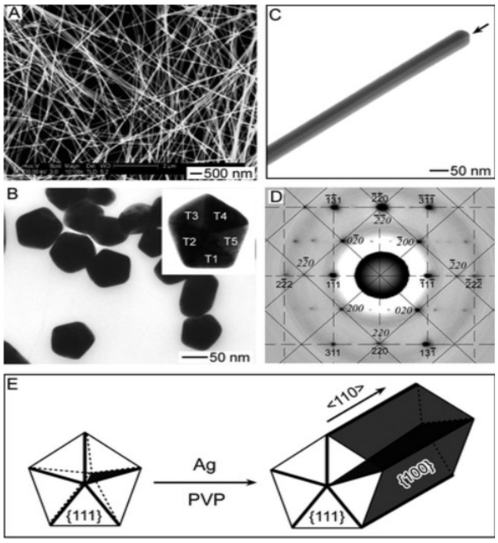

Figure 2. Properties of Silver Nanowires as Determined by Their Structure

3.2. Preparation of Silver Nanowires

There are various ways to prepare silver nanowires, and according to the most basic classification, they can be roughly divided into three basic methods: aqueous solution method, gas-phase method, and template method, as detailed below.

3.2.1. Aqueous Solution Method. In this method, appropriate amounts of silver salt and reducing agent should be dissolved in water to formulate a salt solution containing metal ions. Subsequently, under certain reaction conditions, the reducing agent is slowly dripped into the solution with a dropper, at which time the silver ions are gradually reduced to form silver nanowires. This method is simple to prepare and the final product, silver nanowires, has good morphology and crystallization properties.

3.2.2. Gas-Phase Method. This method involves thoroughly mixing a compound containing silver ions with a reducing agent, then evaporating the mixture into a gas under high-temperature heating conditions and feeding it into a reaction vessel. Finally, silver nanowires are generated through a series of catalyzes and reactions. This can generate silver nanowires at the fastest rate with some controllability.

3.2.3. Template Method. The template method for the preparation of silver nanowires is now a more mature technology, which is more like an extension of the vapor phase method. It requires selecting a material with a regular porous structure (such as polymer film, metal oxide film, etc.) as a template, depositing metal ions on the surface of the template by some means, and finally generating silver nanowires in the pores of the template by reduction and heat treatment. The silver nanowires prepared by this method are highly oriented and regular in structure, and the product is highly controllable.

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4. Interference in the Preparation of Silver Nanowires and the Solutions

4.1. High Junction Resistance and the Solutions

High junction resistance is common in silver nanowire applications, and the capillary force soldering mechanism provides an effective solution. By utilizing capillary forces to reduce the junction resistance, the electrical conductivity of silver nanowires can be significantly improved.

4.1.1. High Junction Resistance due to Easy Loose Stacking of Silver Nanowires. The loose stacking of silver nanowires is conducive to the formation of high junction resistance at the wire junction, which has the potential to impede the practical application of these materials [5]. In order to address the aforementioned issues, a number of potential solutions have been proposed. These include mechanical pressing, high-temperature annealing, laser ablation, welding technology, and so forth. Although these solutions have yielded some positive results, there are still some significant shortcomings. The fine structure of silver nanowires is somewhat susceptible to damage, particularly when subjected to mechanical pressing. This is due to the inherent fragility of the nanowire structure, which is susceptible to deformation under pressure. In the case of a heat-sensitive substrate plate, high-temperature annealing is not a viable option. Laser ablation is currently the most reliable technique, but it is prohibitively expensive. Welding-related techniques necessitate a highly controlled experimental environment to prevent the degradation of silver nanowires and maintain product purity. However, the chemical reagents used in chemical welding often result in the residual contamination of the substrate, which can significantly impact the performance and purity of the final product.

4.1.2. Capillary Force Welding Mechanisms. It is of paramount importance to develop a simple, low-cost, environmentally friendly drag reduction process that does not require specific equipment. Previous studies have demonstrated that capillary phenomena can be employed to prepare silver nanowires, where capillary action exerts a force of approximately 10 MPa to 1 GPa on two particles [6]. Spraying or even human exhaled moisture can reduce the junction resistance between the nanowires. A more detailed examination of the capillary force welding mechanism in the context of silver nanowire preparation reveals that the degree of wetting of the substrate surface exerts a significant influence on the formation of silver nanowires under the action of capillary force welding. In the case of a hydrophilic substrate, the magnitude of the capillary force between silver nanowires and their surfaces is considerably larger than that between the nanowire junctions. Furthermore, the capillary force between nanowire junctions is considerably larger than that between nanowire junctions. In the case of hydrophilic substrates such as polyethylene terephthalate (PET), the nanowires on the surface of these materials exhibit a reduction in resistance due to the capillary forces between the junctions. However, the morphology of the silver nanowires at the junctions remains unaltered.

The advantages and principles of capillary force welding of silver nanowires have profoundly inspired the use of a hydroxyethyl cellulose (HEC) solution with a lower mass fraction instead of water. This approach can reduce junction resistance by capillary-like force action, while at the same time, due to the excellent film-forming property of hydroxyethyl cellulose, it can be covered on the surface of the silver nanowire network to form a layer of a dense protective film and improve its stability. In the actual preparation process, as shown in Figure 3, the silver nanowire conductive network should be spin-coated on the surface of the PET substrate, and then the HEC solution should be uniformly coated to obtain the HEC-AgNWs-PET composite electrode. Following the preparation process, the surface roughness and transmittance of the HEC-coated and uncoated HEC products were characterized and tested. The results demonstrated that the final HEC-coated products exhibited excellent electrical conductivity and transmittance, overcoming the limitations of silver nanowires in terms of low resistance and high transparency.

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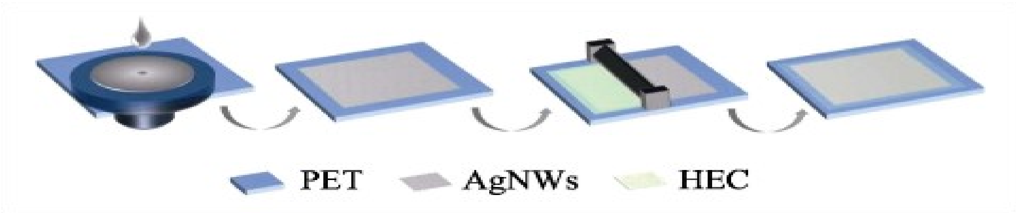

Figure 3. Preparation of Silver Nanowires with PET

4.2. Thermal Stability Problems of Composite Films and The Solutions

The thermal stability of silver nanowire composite films depends on the polymer matrix and coating process used. The use of materials and techniques with excellent thermal stability, such as polyimide matrices and low-temperature atomic layer deposition, can significantly improve the thermal stability and other properties of silver nanowires.

4.2.1. Thermal Stability Problems. It is not the case that all composite membranes have good thermal stability. Despite the significant advantages of composite films in the preparation process, not all polymer films can achieve satisfactory results. It has been demonstrated that the incorporation of AgNW into a heat-resistant acrylate matrix as a film heater for a period of approximately five minutes at a limiting temperature of up to 230°C [8] does not yield results that can be attributed to the inherent thermal stability of The incorporation of AgNW into a thermally stabilized polymer matrix results in a temperature-dependent increase in sheet resistance, which in turn affects the experimental results. This phenomenon can be attributed to the dominant role of the nano-size effect in the observed increase in resistivity.

4.2.2. Polyimide Substrates and Low-Temperature atomic Layer Deposition Techniques. The selection of polyimide with exceptional thermal stability as the polymer matrix to be incorporated into the coated AgNWs ensures that the final product effectively addresses the thermal stability challenges associated with both AgNWs and the polymer matrix. The final products thus produced exhibit low surface roughness, maintain long-term thermal stability at temperatures up to 300°C, demonstrate mechanical flexibility, exhibit atmospheric corrosion resistance, exhibit surface conductivity and surface smoothness, and the colorless polymer material exhibits excellent visual transparency in the final product. In addition to the proper polymer coating, it was discovered that the low-temperature atomic layer deposition (ALD) process of coating protective metal oxides, such as zinc oxide, around silver nanowires can also enhance the thermal stability of AgNW while maintaining the porous structure of the resistors, as shown in Figure 4. The low-temperature ALD technique applied to silver nanowires has been demonstrated to enhance the thermal stability of AgNW [9][10], although there is a paucity of experimental data and reports surrounding the preparation of silver nanowires by low-temperature ALD.

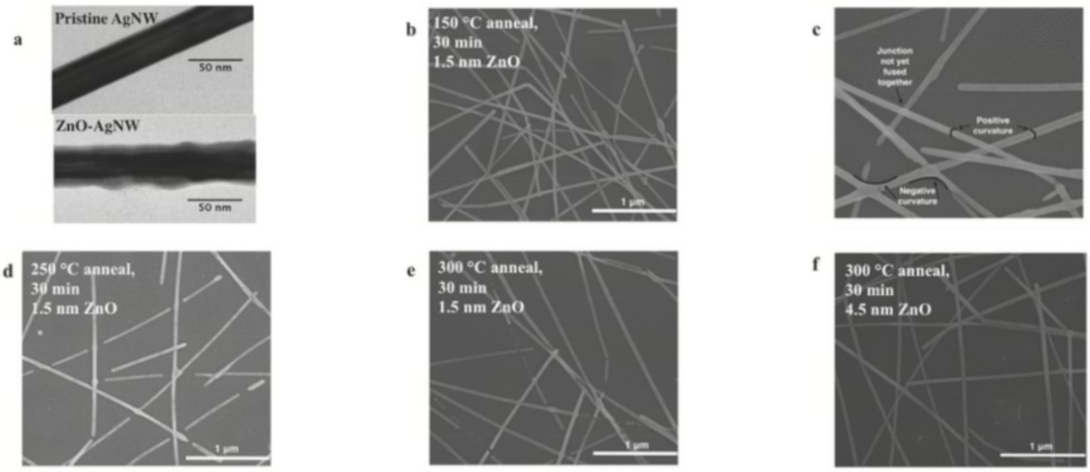

Figure 4. Application of Low Temperature ALD Technology in Silver Nanowire Preparation

5. Conclusion

This paper examines the preparation methods of two-dimensional assemblies nanowires and the interference problems they face in their applications. Different preparation processes are analyzed in detail in order to improve the uniformity, stability and electrical properties of nanowires. It is demonstrated that the implementation of reasonable process regulation and material optimization can markedly diminish the interference factors during nanowire assembly, thereby enhancing the feasibility and reliability of its practical application. Furthermore, this study presents an overview of the current major challenges in nanowire preparation and application, and also establishes the foundation for the design and development of novel nanodevices. In conclusion, two-dimensional assemblies nanowires, a cutting-edge nanomaterial, have a promising future in a wide range of applications. It is anticipated that significant breakthroughs will be made in the fields of electronic devices, sensors, and energy through the continued improvement of preparation techniques and in-depth study of their interference problems. Future research should continue to focus on the optimization of the properties of nanowires and the new challenges in practical applications in order to promote the continuous development of this field.

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