Progress in Preparation Methods and Applications of Inorganic Nanoparticles

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Abstract—Nanotechnology is a new technology with great potential. It can be combined with many physical, chemical and biological methods to develop many nanomaterials with good properties, such as nanoparticles, nanofilms and nanoemulsions. Combining with the domestic and foreign research literatures, this article summarized the preparation methods and applications of the inorganic nanoparticles, introduced the solvothermal method, sol-gel method, thermal decomposition, electrochemical deposition and other preparation methods in detail, as well as application in catalysis, drug delivery, chemical energy storage. The research status and the development direction of inorganic nanoparticles were summarized and prospected, which might be contributed to the future research of nanoparticles.

1. INTRODUCTION
Nanotechnology is one of the hotspots in scientific research, which has been applied in many fields such as physics, chemistry, bio pharmacy and medical tests. Nano materials are defined as materials which has at least one dimension is in the range of 1-100 nanometers in three dimensions.[1] They have better properties than ordinary block metals in many aspects, such as surface area, particle size, fusion point and optical performance. For instance, nano materials have larger specific surface area, so nanoparticles have high surface activation property. In addition, because of the change in the change in the size of nanoparticles, some properties of materials have changed. For example, the surface electronic properties of nano metal particles are quite different from that of ordinary block metals. These unique effects of nanoparticles have a great impact on physical and chemical properties, optical properties and so on, so that nanoparticles get extremely high research value.[1]

2. PREPARATION METHOD OF NANOPARTICLES

2.1. Solvothermal method
Solvothermal method generally worked in high-temperature and high-pressure closed reactors. Raw materials dissolved in organic solvents and form cores. Then the cores grow and finally constitute grains with certain morphology. The disadvantage of this method is that the reaction process is relatively slow and the advantage is preventing the trivialization of toxic substances because of the using of organic solvent as medium. The Fe3O4 sub-microspheres have been embedded uniformly into the reduced graphene oxide (rGO) to form a new-type Conductive 3D network structure complex Fe3O4/rGO through a one-pot solvothermal method.[5]
In addition, composite nanomaterial PANI-Fe₃O₄ can also be prepared through this method. When Fe₃O₄ nanoparticles (particle size less than 15 nm) are loaded on PANI nanolayers, their magnetic and electrochemical properties are enhanced a lot, which allow them to serve as ideal candidates for biomedical applications (such as nucleic acid extraction, cancer diagnosis and treatment, biosensors and drug delivery) and electrode materials.[6] Prepare Fe₃O₄/C composite micron bar using solvent-thermal synthesis and magnetic field induction assistance. In the initial phase, small Fe₃O₄ nanoparticles gather together under the action of glucose, meanwhile, glucose and ethyl diamine are adsorbed as carbon sources on the surface of iron Fe₃O₄ nanoparticles to reduce the total surface energy of nanoparticles and the ethylysis molecule also plays a role in regulating the process of dissolving the reaction material and the formation of nanoparticles to influence the properties of nanoparticles.[7][8] Fe₃O₄@Cu@Cu₂O nanocomposite can also be prepared using solvent-thermal synthesis method. These nanoparticles have a uniform spherical structure with an average particle size of about 50 nm and exhibited highly efficient peroxidase-like activity. In addition, this kind of new nanocomposites has good separation, stability and reusability, could be easily recycled from by a magnet and reused without significant loss of its catalytic activity, it has the potential to replace natural peroxidase in practical applications.[9]

2.2. Sol-gel method
Sol-gel method works by dispersing the coated material in the precursor solvent uniformly and causes its gelation to get nanomaterials with core-shell structure. The most important point for fabricating the core-shell nanomaterials is the regulation of material of their shell. The formation of a shell is generally divided into two steps, including hydrolysis and condensation of the precursor. For instance, in order to prepare multi-functional nanoparticles Fe₃O₄@TiO₂ and Fe₃O₄@SiO₂, the key to success is the rational control of hydrolysis and condensation reaction dynamics, heterogeneous materials gather quickly on surfaces of cores and form shells, thus core-shell nanoparticles are obtained.[10] The core-shell nanoparticles are designed and prepared with sol-gel method, which can control the thickness of the shell by regulating the reaction time and the proportion of the reaction material, thus affecting the size of the whole particle.[11]

2.3. Thermal decomposition
Using the thermal decomposition method, organic solution is firstly prepared and water bath heated to boiling point, then weighed precursor added and stirred to dissolve, finally, under the action of surfactant, nanoparticles are formed. The advantage of thermal decomposition is that the size and appearance of the sample can be controlled during the reaction process, the particle size distribution of the sample is narrow and the preparation time is relatively short, so the functional nanoparticles can be prepared efficiently according to the experimental needs. The disadvantage is because with the effect of surfactant and the experimental environment is complex, the reaction equipment need to be filled with protective gas to eliminate oxygen, and it is sensitive to temperature and need to maintain at 300℃ to 400℃, generally also need to complex surface functionalization. Nanoparticles of dual-functional core-shell structures with both magnetic and fluorescent properties can be prepared by thermal decomposition.[12] The luminescence intensity of fluorescence can be significantly improved by mixing Mn²⁺ into nanoparticles. Different sizes and shapes of nanoparticles can be obtained by thermal decomposition method, through four processes and adding the mixture of rare-earth trifluoroacetic acid and sodium trifluoroacetate in the surfactant, work at different experimental temperatures by regulating the proportion of sodium and rare earths and reaction time.[13]

2.4. Electrochemical deposition method
Electrochemical deposition generally refers to a method of preparing core-shell nanoparticles in the presence of an external electric field, which usually use electric organic polymers or inorganic materials as raw materials. During the deposition, the shell material is deposited on the surface of the core material. The core material can be used as an electrode or an electrolyte to form a core material through
electrostatic attraction. When the reaction is carried out in the solution, the proportion of the material, the amount of charge, the pH of the solution and other factors can be regulated to control the thickness of the shell layer. [14]

3. THE APPLICATION OF NANOPARTICLES

3.1. Catalytic application
Because of the advantages of high activity, low cost, environmental friendliness and selectivity, core-shell nanoparticles can be used in a variety of catalytic reactions. It has important practical application value in nano catalysis, magnetic auxiliary catalysis and integrated catalysis, so as to reduce waste, improve utilization rate and increase reaction speed, which is conducive to sustainable development. It mainly has the three following characteristics: Firstly, the core of nanoparticles can be used as catalyst template to obtain hollow structure, which has higher porosity and surface area and have great future in catalyst application. Secondly, the synergistic effect of core material and shell material can improve its catalytic ability. Thirdly, the performance combination of core material and shell material can broaden the application field of materials (for example, magnetic material @ catalytic material) can be used many times while maintaining its activity, improving its recycling efficiency, and achieving sustainable development).[15]

3.2. Application of drug delivery system
The new generation of drug delivery system should have not only higher loading rate and embedding rate, good biocompatibility and controlled release ability, but also have targeting ability. Targeted release characteristic can improve the therapeutic effects of drugs, also keep drug molecules from being released until they reach the action site so the toxic effects on normal cells are reduced. Mix Fe3O4 into core shell materials, take advantage of its magnetic compatibility and biocompatibility, chemical modifiability and low toxic side effects, therefore in the field of drug control, the problem of drug targeted release will be better solved. Yang et al.[16] prepared core-shell nanoparticles (Fe3O4@mSiO2) with iron tetroxide as the core and mesoporous silica as the shell. This kind of nanoparticles works as delivery vectors to carry anti-cancer drugs Adriamycin and nitrogen mustard phenylbutyrate. After the drug is loaded onto the carrier, hyaluronic acid (HA) is used to contribute a layer of cross-linked gel outside the nanoparticles to prevent drug diffusion. The release kinetics revealed the controlled release reaction induced by HA, which is a major enzyme present in the tumor microenvironment and can degrade HA outside the nanoparticles so that the internal anti-cancer properties get released. In addition, many tumor cells have HA receptors that further enhance the delivery of specific targeted drugs.

3.3. Application in electrochemical energy storage
Capacitor is one of the components of energy storage system, which play an important role in the field of energy storage for a long time. Capacitors with such a structure can improve their electrochemical storage performance by selecting different materials, selecting appropriate materials and designing special structures through certain methods. Because the core of the core-shell nanoparticles is covered by a layer of shell material, the stability and capacitance of the core get changed, and it has porous channel, high power transmission, long cycle stability structure and good conductivity. Zhao et al.[17] prepared a kind of Fe3O4@C nanoparticles with core-shell structure (Fe3O4 accounted for 90 wt%), and be used as the anode material of the new lithium battery. After 70 cycles, specific charge capacity of the Fe3O4@C composite still remained at 750 m Ah/g, with a small capacity loss of 0.25% per cycle. Meanwhile, the columbic efficiencies of this composite remained at a high value of approximately 99% during cycles, thus this new kind of core-shell nano-material have great potential in electrochemical energy storage.
4. CONCLUSION

Finally, although the field of nanoparticles has made a lot of progress and achievement, research about nanoparticles still facing some problems and challenges, such as quick and easy production of core-shell nanoparticles with uniform particle size distribution, high crystallinity and strong magnetic or electrical signal response, and the reduction of production cost and application in practical production and industrial application. In addition, further study is needed about the interaction between nanoparticles and biological macromolecules, deeply understand their mechanism of action, and whether they have toxic and side effects on human body, so as to expand new applications in the field of biomedicine. With the development and progress of science and the urgent need for new materials, the development of nanotechnology and nanomaterials will get important research significance and practical value.

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