RESEARCH ARTICLE

Nanometer Materials & Nanotechology and T heir Application Prospect

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Abstract: Due to the unique surface effect, volume effect and quantum size effect of nanomaterials, the electrical, mechanical, magnetic, optical and other properties of the materials have produced amazing changes. At present, nanotechnology has become one of the hotspots of scientific research. The application of nanotechnology in the future will far exceed the computer industry or genetic medicine, and become the core of the information age in the 21st century. The thesis introduced in detail the characteristics of nanomaterials and the broad application prospects of nanotechnology in the fields of electronics, ceramics and chemical engineering.
Keywords: Nanomaterials; quantum size effect; fine ceramics; nanotechnology; application prospects

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1 Introduction

Broadly speaking, nanomaterials refer to materials that are at least one dimension in the meter-scale range (1-100nm) in a three-dimensional space or are composed of them as basic units. The basic unit mentioned here includes zero-dimensional nanoparticles, one-dimensional nanowires and two-dimensional nano-films.

The properties of nanomaterials are closely related to the properties of their constituent units (1-100nm particles). And these nano-particle systems between the micro and the macro are regarded as a new kind of material level. Many unique properties have emerged. Nanomaterials research is currently a hot spot in materials science research, and the correspondingly developed nanotechnology is recognized as the most promising scientific research field in the 21st century.

2 Characteristics of nanomaterials

2.1 Surface effects of nanomaterials

The surface effect refers to the change in properties caused by the ratio of the number of atoms on the surface of a nanoparticle to the total number of atoms, which increases sharply as the particle diameter becomes smaller.

The particle size below 10nm will rapidly increase the proportion of surface atoms. When the particle size is reduced to 1nm, the proportion of surface atoms reaches more than 90%, and the atoms are almost all concentrated on the surface of the nanoparticles. Due to the increase in the number of surface atoms of nanoparticles, insufficient coordination number of surface atoms and high surface energy, these atoms are easy to combine with other atoms and stabilized, so they have high chemical activity.

2.2 Volume effect of nanomaterials

Due to the small size of the nanoparticle, it contains a small number of atoms. Therefore, many phenomena cannot be explained by the properties of bulk materials that usually have infinite atoms. This special phenomenon is usually called the volume effect. Among them, the famous Kubo theory is a typical example of volume effect. Kubo theory is based on the distribution of electronic energy levels near the Fermi surface of metal nanoparticles. Kubo regards the electronic state of metal nanoparticles near the Fermi surface as a degenerate electronic state restricted by size, and further assumes that their energy level is the discontinuous energy level of the quasi-particle state. The relationship between the diameter d of metal nanoparticles is: $= 4E_F / 3N \propto V^{-1} \infty 1/d^3$ (1)

Among them, N is the total number of conducting electrons of a metal nanoparticle; V is the volume of the nanoparticle; EF is the Fermi level. As the diameter of the nanoparticle decreases, the energy level interval increases, electrons are difficult to move, and the resistivity increases, so that the energy gap becomes wider, and the metal conductor will become an insulator [1].

2.3 Quantum size effect of nanomaterials

When the size of the nanoparticle drops to a certain value, the electron energy level near the Fermi surface of the metal particle changes from quasi-continuous to discrete energy level; and nano-semiconductor particles have discontinuous highest occupied molecular orbital energy levels and lowest unoccupied energy levels. The phenomenon that the energy level of the molecular orbital widens the energy gap is called the quantum size effect of nanomaterials. The volatility of electrons in discrete quantized energy levels in nanoparticles brings a series of special properties of nanoparticles, such as high optical nonlinearity, specific catalytic and photocatalytic properties, etc. When the size of the nanoparticle is equivalent to the wavelength of the light wave, the De Broglie wavelength, the coherence length of the superconducting state or the penetration depth of the magnetic field or less, the periodic boundary conditions of the crystal will be destroyed, and the particle surface layer of the amorphous nanoparticle The density of nearby atoms decreases, resulting in abnormal sound, light, electricity, magnetism, and thermodynamic properties. For example, the light absorption increases significantly, the superconducting phase changes to the normal phase, the melting point of the metal decreases, and microwave absorption is enhanced. Using the property that the plasmon resonance frequency shift varies with the particle size, the particle size can be changed, the displacement of the absorption edge can be controlled, and microwave absorbing nanomaterials with a certain bandwidth can be manufactured for electromagnetic wave shielding, stealth aircraft, etc.

Due to the refinement of nanoparticles, the number of grain boundaries has increased significantly, which can greatly improve the strength, toughness and superplasticity of the material. The response of its structured particles to light, mechanical stress and electricity is completely different from that of micron or millimeter-level structured particles, which makes nanomaterials show many wonderful properties at the macro level, for example: the strength of nanophase copper is 5 times higher than that of ordinary copper; nanometer The toughness of phase ceramics is extremely high, which is completely different from ordinary ceramics composed of large particles. Nanomaterials have fundamentally changed the structure of materials, and it is expected that a new generation of materials such as high-strength metals and alloys, plastic ceramics, intermetallic compounds, and atomic-scale composite materials with specific properties can be obtained. The problem solved opens up new ways.

2.4 Small size effect

The small size effect means that when the size of the particle is equal to or smaller than the wavelength of the light wave, the De Broglie wavelength for conducting electrons, the coherence length of the superconducting state, and the transmission depth, the periodicity condition will be destroyed. The characteristics of sound, light, electromagnetic and thermodynamics will all change. For example, the light absorption increases significantly and produces the plasmon resonance shift of the absorption peak; the transition from the magnetic order state to the magnetic disorder state, and the superconducting phase to the normal phase; the transition of the phonon spectrum. For 2nm gold particles. Under a high-resolution electron microscope, it can be observed that its morphology changes continuously between single crystals and multiple twins. This is different from the usual melting phase transition, which is a quasi-melting phenomenon of small-sized particles. For nano-scale ferromagnetic particles [2]. Such as Fe-Co alloy. When the particle size is the critical size of a single domain, it can have a very high coercivity and can be used for magnetic credit cards, magnetic keys, etc. Due to the small size effect, the melting point of some metal nanoparticles is much lower than that of bulk metals. For example, the melting point of 2nm gold particles is 600K, and the bulk gold is 1337K, and the melting point of nano-silver powder can be reduced to 100°C.

2.5 Macroscopic quantum tunneling effect

The tunneling effect is one of the basic quantum phenomena, that is, when the total energy of a microscopic particle is less than the height of the barrier, the particle can still pass through the barrier. In recent years, it has been discovered that some macroscopic quantities, such as the magnetization of microparticles, the magnetic flux and charge in quantum coherent devices, also have a tunneling effect. They can pass through the potential well of the macroscopic system to produce changes, so it is called the macroscopic quantum tunneling effect. The macroscopic quantum tunneling effect and the quantum size effect together determine the limit of further miniaturization of microelectronic devices, and also limit the shortest time for information storage using magnetic tapes.

3 Research status and achievements of nanotechnology in China

Nanotechnology is an emerging science and technology with the most potential for market applications. Its potential importance is undoubtedly. Some developed countries have invested a lot of money in research. For example, the

United States first established the Nano Research Center, and the Japanese Ministry of Education, Science and Technology listed nanotechnology as one of the four key research and development projects in materials science. In Germany, with Hamburg University and Mainz University as the nanotechnology research center, the government invests 65 million US dollars each year to support the research of microsystems [3]. In China, many scientific research institutes and universities also organize scientific research forces to carry out research on nanotechnology work, and achieved certain research results, mainly as follows.

The synthesis of aligned carbon nanotube arrays was completed by researcher Xie Sishen, Institute of Physics, Chinese Academy of Sciences. They used the chemical vapor method to efficiently prepare carbon nanotubes with a pore size of about 20nm and a length of about 100m. And thus fabricated a nanotube array with an area of 3mm×3mm, carbon nanotubes, the distance between the tubes is 100m.

The preparation of gallium nitride nanorods was completed by Professor Fan Shoushan from Tsinghua University. They used carbon nanotubes to prepare semiconductor gallium nitride one-dimensional nanorods with a diameter of 3-40nm and a length of micrometers for the first time, and proposed the concept of carbon nanotubes to limit the reaction. And cooperated with Professor Dai Hongjie of Stanford University in the United States to realize the self-organized growth of carbon nanotube arrays on silicon substrate for the first time in the world.

Quasi-one-dimensional nanowires and nanocables were completed by researcher Zhang Lide from the Institute of Solid State Physics, Chinese Academy of Sciences. They used carbothermic reduction, sol-gel soft chemistry, combined with new technologies such as nano-droplet epitaxy to synthesize tantalum carbide nanowire outsourcing insulator SiO_2 nanocable for the first time.

The production of nano-diamonds by catalytic pyrolysis was done by Qian Yitai of the University of Science and Technology of China and others. They used catalytic pyrolysis to react carbon tetrachloride and sodium to prepare diamond nanopowders. However, compared with the advanced technology of foreign developed countries, we still have a big gap. The German Ministry of Science and Technology once predicted the future market potential of nanotechnology: They believe that by 2000, the market capacity of nanostructured devices will reach 637.5 billion U.S. dollars, and the market capacity of nanopowders, nanocomposite ceramics and other nanocomposite materials will reach 545.7 billion. US dollars, the market capacity of nano processing technology will reach 44.2 billion US dollars, and the evaluation technology market capacity of nano materials will reach 2.72 billion US dollars. It also predicts that market breakthroughs may be in the fields of information, communications, environment and medicine.

4 Application and prospects of nanotechnology

4.1 The application of nanotechnology in the field of microelectronics

Nanoelectronics is an important part of nanotechnology. Its main idea is to design and prepare nano-quantum devices based on the quantum effects of nanoparticles. It includes nano-ordered (disordered) array systems, nano-particles and microporous solid assembly systems, Nano-superstructure assembly system. The ultimate goal of nanoelectronics is to further reduce integrated circuits and develop various devices composed of single atoms or single molecules that can be used at room temperature.

At present, various nano-devices have been successfully developed using nanoelectronics. Single-electron transistors, tunable nano-light-emitting diodes with three primary colors of red, green, and blue, and ultra-micro magnetic field detectors made of nanowires and giant magnetoresistance effects have come out. Moreover, the successful development of carbon nanotubes with peculiar properties has played a key role in the development of nanoelectronics.

Carbon nanotubes are formed by curling layers of graphite carbon atoms, and the radial scale layer is controlled below 100nm. The movement of electrons in the carbon nanotubes is restricted in the radial direction, showing a typical quantum confinement effect, but there is no restriction in the axial direction. Using carbon nanotubes as a model to prepare one-dimensional semiconductor quantum materials is not a hypothetical idea. Professor Fan Shoushan of Tsinghua University uses carbon nanotubes to confine the gas phase reaction within the nanotubes to grow semiconductor nanowires. They put the $Si\text{-}SiO_2$ mixed powder in the bottom of the crucible in the quartz tube, heated it and introduced N_2. SiO gas reacts with N_2 to grow SiN nanowires in carbon nanotubes, the radial size of which is 4-40nm[4]. In addition, in 1997, they also prepared GaN nanowires. In 1998, the research group cooperated with Stanford University in the United States to realize the self-organized growth of carbon nanotube arrays on a silicon substrate for the first time in the world. It will greatly promote the application of carbon nanotubes in field emission plane displays. Its unique electrical properties enable carbon nanotubes to be used in large-scale integrated circuits, superconducting wires and other fields.

As early as 1989, IBM scientists had used the probe on the tunnel scanning microscope to successfully move the xenon atom and used it to spell the three letters of IBM. Japan's Hitachi company has successfully developed a single electronic transistor, which performs a specific function by controlling the motion state of a single electron, that is, an electron is a multi-functional device. In addition, the NEC Research Institute in Japan has the technology to fabricate fine quantum wire structures below 100nm, and successfully fabricated quantum dot arrays with switching functions on GaAs substrates.

The University of Wisconsin in the United States has produced quantum dots that can hold a single electron. Billions of such quantum dots can be accommodated on a single needle tip. The use of quantum dots can be made into single-electron devices with small size and low energy consumption, which will be widely used in the fields of microelectronics and optoelectronics. In addition, if billions of quantum dots can be connected, each quantum dot has the function of a nerve cell in the brain, and combined with the MEMS (microelectromechanical system) method, it will bring hope to the development of intelligent microcomputers. , To achieve a revolutionary breakthrough in information collection and processing capabilities [5].

4.2 The application of nanotechnology in the field of ceramics

As one of the three pillars of materials, ceramic materials play a pivotal role in daily life and industrial production. However, due to the brittle texture, toughness and strength of traditional ceramic materials, its application has been greatly restricted. With the wide application of nanotechnology, nano-ceramics are produced, hoping to overcome the brittleness of ceramic materials and make ceramics have the same flexibility and workability as metals. Cahn, a famous British material expert, pointed out that nano-ceramics is a strategic way to solve the brittleness of ceramics.

The so-called nano-ceramics refers to ceramic materials whose phases in the microstructure have nano-scale, that is to say, the grain size, grain boundary width, second phase distribution, defect size, etc. are all on the nano-scale level. To prepare nano-ceramics, it is necessary to solve: control of powder size, morphology and distribution, control and dispersion of agglomerates, control of block morphology, defects, roughness and composition.

Gleiter pointed out that if polycrystalline ceramics are composed of grains of a few nanometers in size, they can become ductile at low temperatures, and the application prospects of nanomaterials and their technology can undergo 100% plastic deformation. And it was found that the nano-TiO_2 ceramic material has excellent toughness at room temperature, and withstands bending at 180℃ without cracking. Many experts believe that if it can solve the technical problem of inhibiting crystal grain growth during the sintering process of single-phase nano-ceramics, and thus control the nano-ceramics with the ceramic grain size below 50nm, it will have high hardness, high toughness, and low temperature ultra Unparalleled advantages of traditional ceramics such as plasticity and easy processing. The Shanghai Institute of Ceramics found that after the nano 3YTZP ceramic (about 100nm) was subjected to a room temperature cyclic tensile test, the fracture area of the sample had local superplastic deformation, and the deformation was as high as 380%, and a large amount of it was observed from the side of the fracture. Usually appear in the slip line of the metal fracture. Tatsuki et al. conducted tensile creep experiments on the prepared Al_2O_3-SiC nanocomposite ceramics, and found that with the slip of the grain boundary, the nano SiC particles at the Al_2O_3 grain boundary rotate and are embedded in the Al_2O_3 grains, thereby enhancing The resistance of grain boundary sliding is improved, which also improves the creep ability of Al_2O_3-SiC nanocomposite ceramics.

We have used chemical co-precipitation combined with a new high-frequency plasma baking process to prepare nano-ZnO and corresponding additive ceramic composite powders. TEM analysis results show that the particle size of the ceramic composite powder is less than 100nm. Through proper impurity ratio and sintering at about 1100℃ , a dense porcelain body can be obtained, the varistor voltage can reach about 480V/mm, and the nonlinear coefficient can reach 52.

Although nano-ceramics still have many key technologies to be solved, its excellent room temperature and high temperature mechanical properties, bending strength, fracture toughness, make it widely used in cutting tools, bearings, automobile engine parts, etc. Many ultra-high temperature, strong corrosion and other harsh environments play an irreplaceable role for other materials and have broad application prospects.

4.3 Application of Nanotechnology in the Field of Bioengineering

As we all know, a molecule is the smallest unit that keeps the chemical properties of a substance unchanged. Biomolecules are very good materials for information processing. Each biomacromolecule itself is a micro-processor. The molecules undergo state changes in a predictable manner during movement. The principle is similar to that of a computer.

Logic switches, using this feature and combining nanotechnology, can design quantum computers [6]. Dr. Adelman of the University of Southern California and others applied biological experimental methods based on DNA molecular computing technology to effectively solve the current problem "Hamilton path problem" that cannot be solved by computers, enabling people to understand the information processing function of biological materials and the calculation of biological molecules. There is a further understanding of technology.

Although molecular computers are currently only at an ideal stage, scientists have considered using several biomolecules to make computer components, among which bacterial rhodopsin is the most promising. The biological material has specific thermal, optical, chemical and physical properties and good stability, and its peculiar optical cycle characteristics can be used to store information, thereby playing a role in replacing current computer information processing and information storage. During the entire photocycle process, the bacterial rhodopsin undergoes several different intermediate processes, accompanied by corresponding changes in the material structure. Birge et al. studied the bacterial vision

The potential parallel processing mechanism of the magenta molecules and the potential to be used as a three-dimensional memory. By tuning the laser beam, the information is written into and read from the bacteriorhodopsin cube in parallel, and the bacteriorhodopsin three-dimensional memory can provide much larger storage space than the two-dimensional optical memory.

So far, no commercial molecular computer components have appeared. Scientists believe that the key to improving integration and manufacturing microcomputers is to find micro devices with switching functions. Syracuse University in the United States has used bacterial rhodopsin proteins to make light-guided AND gates, and light-emitting gates to make protein storage. In addition, they also use bacterial rhodopsin protein to develop a central network and associative storage device that simulates the associative ability of the human brain.

The advent of nanocomputers will make a qualitative leap in the current information age. It will break through the traditional limit, increase the storage and information processing capacity of unit volume material by millions of times, thus realizing another revolution in electronics.

5 Conclusion

In short, nanotechnology is becoming the focus of attention in the scientific and technological circles of various countries. As predicted by Academician Qian Xuesen: "the structures around and below nano will be the characteristics of scientific and Technological Development in the next stage, will be a technological revolution, and will be another industrial revolution in the 21st century."

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