

NANOSCALE RARE EARTH METAL OXIDE SEMICONDUCTOR, PROPERTIES, PREPARATION METHODS, AND ITS APPLICATIONS

Abstract

When reduced to the nanoscale, the properties of metal oxide semiconductor materials significantly change due to their enormous surface area or quantum size effect. Nanostructured metal oxide semiconductor materials have good redox properties. The development of a mixed hydroxide material that can be electrochemically activated has led to the creation of a metal oxide semiconductor with synergistic catalytic effects for the oxidation of hydroxyapatite. Rare earth lanthanide metals like (La, Ce, Pr, and Nd) have recently been discovered to be well-known catalysts for oxidation reactions as well as a potential candidate as a stabilising agent of hydroxyapatite in the crystalline phase. This chapter covered a variety of nanomaterial synthesis techniques, as well as its characteristics and uses.

Keywords: Rare earth metal oxides
Quantum size effect, Lanthanide series
Catalytic activity, Semiconductors
Cerium oxide

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I. INTRODUCTION

The study of materials with extraordinary characteristics, functions, and phenomena at the nanoscale is known as nanoscience. Nanotechnology refers to the real-world uses of scientific advancement and its economic ramifications. Utilizing molecular properties, the objective is to maximise its effectiveness. It emphasises properties like strength, lightness, reactivity, electrical conductivity, and thermal conductivity to make commercial goods. [1].

It makes use of both top-down and bottom-up methodologies. Numerous concepts, including molecular machines and self-assembly, are used in nanotechnology. Compared to their bulk counterparts, nanoparticles have unique properties. Their sizes, shapes, and compositions may all be easily changed without affecting their features. Depending on the type of material utilised, these advancements emerge from a range of sources rather than merely reducing in size. The surface atom effect and the quantum size effect are the causes.

- 1. Quantum size effect:** The Quantum confinement effect induces changes in bandgap energy and quantization of electronic energy level. When a particle size approaches the Bohr exciton radius, the energy gap becomes widened with the decreasing particle size, and this property will enhance optical properties much.
- 2. Surface atom effect:** The surface atom to bulk ratio sharply rises with decreasing particle size. When material size is reduced to the nanoscale, total surface area per unit mass increases. This is because the uneven surface of nanoparticles provides surface defects that are significantly more active and can give more electronic states and reactivity.
- 3. Properties of nanoparticles:** Nanocrystalline materials with average grain sizes of 100 nm are drawing rising attention from researchers all over the world due to their new characteristics and many potential uses [2]. Because to the microscopic grain size of these materials, and hence the high volume fraction of atoms in or near the grain boundaries, these materials have properties that are often superior, and sometimes unique, in contrast to normal coarse-grained materials. These can affect the optical, electrical, and magnetic characteristics of materials, especially as the structure or particle size approaches the nano-scale. Quantum dots and quantum well lasers for optoelectronics are two materials that use these properties.

Several new advancements to nanoparticle and nanotube assembly synthesis are also now available. Individual nanostructures of semiconductors, metals, and other materials now have greater understanding of their size-dependent electrical, optical, and magnetic properties. Scanning probe microscopies, in addition to well-established technologies like electron microscopy, crystallography, and spectroscopy, have provided powerful instruments for examining nanostructures [3].

Nanostructures bridge the gap between molecules and infinite bulk systems. Individual nanostructures include clusters, quantum dots, nanocrystals, nanowires, and nanotubes, whereas nonstructural material collections comprise arrays, assemblies, and superlattices of the individual nanostructures. Some of the important concerns of materials scientists in the nanoscience area are

- Nanoparticles or nanocrystals of metals and Semiconductors, nanotubes, nanowires, and nanobiological systems.
- Assemblers of nanostructures and the use of biological systems, such as DNA as molecular nanowires and templates for metallic or semi-conducting nanostructures.
- Theoretical and computational investigations that provide the conceptual framework for structure dynamics, response, and transport in nanostructures.
- Application of nanomaterials in biology, medicine, electronics, chemical processes, High - strength materials, etc.

4. Properties of rare-earth metal oxide nanoparticles: A series of rare earth metal oxide (CeO_2 , Pr_2O_3 , and Nd_2O_3) nanoparticles, which have served as a "treasury" of new materials and a "vitamin" for the semiconductor industry, play a crucial role in the advancement of technology and the growth of technical industries. They are also extensively used in high-technology sectors like information and biotechnology [4]. Due to the structure of the 4f orbitals, which are 'buried' inside the atom and protected from the atom's surroundings by the 4d and 5p electrons, rare earth exhibits different chemical properties from the main group elements and transition metals [4,5]. The rare earth has special catalytic, magnetic, and electronic capabilities because of these orbitals. Applications that are not conceivable with transition and main group metals can be made using these peculiar features.

II. NANOPARTICLE PREPARATION METHODS

1. Solution precipitation procession of nanoparticles: Researchers have been drawn to the idea of precipitating clusters of inorganic compounds from a solution of chemical compounds largely due to how easily laboratory studies can be carried out. This is especially true if a dispersible nanoparticulate powder is not the desired outcome but rather a nanocrystalline powder. The capacity to create encapsulated nanoparticles, specifically with an organic molecule, to add functionality to the nanoparticles, improve their stability in a medium, or manage their shape and size is a significant benefit of solution processing [6]. Solution processing can be classified into three major categories

- **Sol-Gel processing:** The sol-gel procedure is one of the most often utilised solution processing techniques for producing metal oxide nanoparticles. Sol-gel processing and solution precipitation have grown synonymous over time, mostly among people on the technical periphery. The two tactics differ greatly from one another, as will be seen below. In the sol-gel processing method, a reactive metal precursor, such as metal alkoxide, is hydrolyzed with water, and the hydrolyzed species are then allowed to condense with one another to produce precipitates of metal oxide nanoparticles. The precipitate is dried and washed before being calcined at high temperatures to produce crystalline metal oxide nanoparticles. The following is the nucleophilic interaction with water that happens during the hydrolysis of metal alkoxides:



- **Precipitation:** Large differences in powder characteristics are possible when producing metal powder using chemical and physiochemical processes. Particle size and form may be tightly controlled thanks to the vast range of manufacturing parameters and processing variables now available. This category includes powders produced from hydride breakdown, thermit reactions, thermal decomposition, precipitation from a solution or a gas, chemical embitterment, and oxide reduction. The most often employed procedures in this category are thermal decomposition and oxide reduction precipitation from solution. This oxide reduction technique is employed for the smaller-scale manufacturing of cobalt and nickel powders, as well as for the creation of refractory metal copper powder and carbide powders.
- **Hydrometallurgical method:** By leaching an ore or ore concentrate and then precipitating the metal from the leach solution, hydrometallurgical processing can produce metal powders. Although the fundamentals of precipitation reactions have been understood for more than a century, commercial use of this technology has not proven successful. Electrolysis cementation or chemical reduction can be used to directly precipitate metal from a solution. By first heating a metal compound, such as during breakdown and reduction, and then precipitating that product, indirect precipitation can be accomplished.

Copper cementation and the separation and precipitation of copper, nickel, and cobalt from their respective salt solutions by reduction with hydrogen are the two most often used commercial hydrometallurgy processors. The simplest kind of copper cementation is the recovery of copper from acidic waste that precipitates as an impure powder in solutions. Such copper powders are used in P/M friction composite components due to the considerable concentrations of iron and silicates, low apparent density, and high green strength. Because there is not enough sintering activity, they are not employed in traditional structural elements.

- **Jet Nebulizer technique of NPS:** As shown in Figure 1 the Jet nebulizer is composed of three primary components that are simple to separate and reassemble.

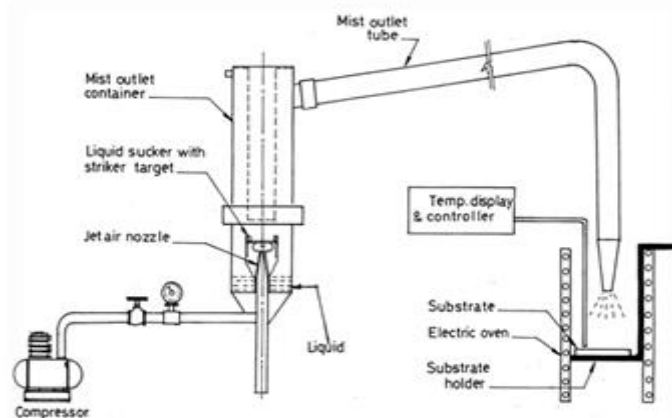


Figure 1: Experimental setup of Jet Nebuliser Technique

The first component is the bottom section, which has a 0.5 mm-diameter micro air nozzle and a compressed air intake. This is the crucial component of the nebulizer. This nozzle behaves like a jet air nozzle and exhales air at a very high speed when air at high pressure is applied through it. This explains why the device is called a "Jet Nebulizer." The first half of the Jet air nozzle is installed in the second section, a specifically made liquid sucking unit with a tiny hole and a striker target tip in the top portion. The third one is the top section, which has a 1 cm diameter tube running from top to bottom as well as an exit for releasing aerosols. Figure 1.2 is a snapshot of an experimental Jet Nebulizer setup.



Figure 2: Photograph of experimental technique

The bottom part of the nebulizer should be filled with the chemical liquid that will be sprayed. The liquid is poured into the tube's upper part through the aperture at the tube's apex. When compressed air is delivered to the bottom section, it is quickly discharged via the Jet air nozzle. As a result of the vacuum created at the junction by the Jet nozzle speed of the air, the liquid in the bottom section will now flow towards the junction of the Jet nozzle and the second portion by capillary rise movement. When the liquid reaches the intersection, it has been mixed with the swift air and is ready to strike the striker's target tip point. The fragmentation of the liquid began as a result of this very fast contact and progressed horizontally in the direction of the first portion's walls. Here, the liquid was further fragmented by a second collision with the side walls, resulting in droplets the size of aerosols that traveled in the direction of the outflow. A tiny vacuum is formed on the top section of the target tip as a result of the contact with the straighter target tip and the horizontal movement of the liquid fragmentations; as a result, the air is automatically drawn via the 1 cm diameter tube in the top portion of the nebulizer. This air was mixed with the mist and traveled quickly in the direction of the outflow.

The mist output coming out from the Nebulizer towards through the specially designed spray nozzle falls on the substrate which is placed inside the furnace maintained with the temperature range of 300°C to 500°C. The distance between the spray nozzle and the substrate is optimized at 5 cm for better coating.

Numerous process factors affect the film's quality, thus it's crucial to optimize each one to produce high-caliber films. The airflow rate and substrate to nozzle distance in the current study were tuned by trial and error. The thermophoretic force acting on the liquid droplet will change as a result of variations in the temperature gradient in the vapor space caused by changes in the distance from the substrate to the nozzle. The essential requirement for the optimal conveyance of the species to the substrate in the Jet nebulizer spray pyrolysis is that when the droplet (mist) reaches the substrate, it should completely evaporate immediately above the substrate. With increasing substrate to nozzle distance, the droplets' thermal energy will grow significantly, supposing that the size distribution of each droplet is uniform. The droplets are therefore preheated by the carrier gas by heat radiation as a result. The pyrolytic process is known to be accelerated by preheating. Therefore, it is likely that a heterogeneous reaction occurs at a substrate to nozzle distance of 5 cm as a result of the pre-heating of the optimal droplet size, which led to the production of films of high quality. The thermal energy acquired by the droplet is quite high above a substrate to a nozzle distance of 5 cm. This results in the water molecule entirely vaporizing distance from the substrate, which is crucial for the pyrolytic decomposition's oxidizing agent. The particle melts and sublimates (or vaporizes), and the vapor phase will experience a chemical reaction. Because all of the reactant and product molecules are in the vapor phase, this reaction is homogenous. The molecules create a powdery deposit on the substrate when they condense as microcrystalline. The layer's development is hampered by this powder, which lowers transmission. Additionally, the homogenous reaction reduces the effectiveness of the deposition [7].

The benefits of Jet nebulizer spray pyrolysis over traditional spray pyrolysis are as follows.

- Relatively low temperature is enough to get good oxide films.
- For device fabrications, less heating effect is required.
- Additional accessories like pretty etc., are not required.
- A small amount of precursor solution is required.
- It also reduced the material quantity.
- Very small, compact, and convenient to spray.

2. Applications of Nano materials: Nanomaterials may be used in a variety of applications due to their unique chemical, physical, and mechanical properties. The apps listed here are simply a selection.

- **Next generation computer chips:** The microelectronics industry has prioritised miniaturisation, which entails lowering the size of circular components like as transistors, resistors, and capacitors. The microprocessor that contains these components may work much faster by lowering their size, allowing computations to be performed at much faster speeds. However, various technological challenges are impeding these improvements, including a scarcity of ultra-fine precursors required to construct these components, insufficient heat dissipation due to the faster speeds of these microprocessors, and a short mean time between failures [8].

- **Better Insulation materials:** Aerogels are foam-like structures formed by the combustion sol-gel synthesis of nanocrystalline minerals. The porous aerogels are extremely light, yet their strength is 100 times that of their weight. Aerogels are three-dimensional, continuous networks of fluid-filled particles. Aerogels are now used for insulation in workplaces, homes, and other structures because they are porous and trap air at their interstices. The use of aerogels as insulation reduces heating and cooling costs dramatically while also saving energy and reducing environmental impact. They are also being used as components for smart windows, which automatically shade when the sun is too bright and brighten when it is not [9].
- **High-sensitivity sensors:** Sensors employ their sensitivity to the many parameter changes that they are designed to monitor. Some of the qualities that may be measured are electrical resistance, chemical activity, magnetic permeability, thermal conductivity, and capacitance. The microstructure of the materials used to manufacture the sensors has a large effect on all of these factors. The sensor material's chemical, physical, or mechanical characteristics can be utilised to determine how the environment surrounding the sensor has changed. In response to a reaction, the sensor's conductivity and capacitance change. A decrease in particle size dramatically accelerates and broadens this reaction. As a result, sensors made of nanocrystalline materials are extremely sensitive to environmental changes. Nanocrystalline sensors are frequently employed in smoke detectors, ice detectors on aeroplane wings, engine performance monitors, and other devices.
- **Large electrochromic display devices:** The double injection of ions and electrons into the nanocrystal, which they mix with, is the process that controls electrochromism. The color gets bleached when the polarity is reversed. The grain size of the tungsten acid gel has a significant impact on the resolution, brightness, and contrast of these devices. As a result, nanomaterials are being studied more broadly for this reason [10]. Because of their better chemical, physical, and mechanical capabilities as well as their exceptional formability, nanomaterials outperform their traditional counterparts.

Nearly every day, new uses are discovered. There are many more uses and applications that have yet to be found. The wide band gap semiconductor material category includes the magnesium tin oxide nanoparticles. These materials have demonstrated adequate performance in a variety of sectors, including solar cells and transparent electrodes for watches.

- **Cosmetics:** The cosmetic sector is one use of nanoparticle technology that has enormous commercial potential. Since the attributes of color and light fastness are accomplished by component mixing in the cosmetic preparation, there is a significant demonstrated need in this area, and the technology may be made simple. The sizable markets for sunscreens and skin rejuvenation products provide the prospect of increased profits [11].
- **Medical/Pharmacology:** Liquid dispersion preparations will be widely used to apply topical coatings to the human epidermis because they can be absorbed faster and more completely than conventional coatings [12].

- **Micro electro-mechanical systems:** MEMS technologies will help the semiconductor sector in particular, but they also have a wide range of other potential uses, including those in medicine, ceramics, thin films, metal alloys, and other specialized fields. Applying sputtering coatings to produce MEMS technology in conjunction with these applications is a particular focus in the United States.
- **Printing:** The qualities of the inks themselves can be controlled by nanoscience in the domains of image capture and image output covered by inkjet technology.
- **Semiconductors:** Thin film for the semiconductor industry is one type of bottom-up technology that is getting a lot of interest.
- **Biological applications:** The primary component of mineral bone is nanosized hydroxyapatite (HA). Bone remodeling is a continuous resorptive-formative process that occurs in living bone. Along with the associated vascular supply, a network of canaliculi and lacunae, and the actions of osteoblasts and osteoclasts, the process includes simultaneous bone repair and removal. Due to its resemblance to the body's hard tissues, HA has remarkable bioactivity and biocompatibility features in bone cells and tissues.

III. CONCLUSION

Advanced materials for several applications, semiconductor nanoparticles have been extensively explored. Semiconductor nanomaterial is well suited for use in emerging technologies such as nanoelectronics, nanophotonics, energy conversion, non-linear optics, miniature sensors and imaging devices, solar cells, detectors, photography, and bio-medicine due to its distinctive physical and chemical properties. Materials preparation, characteristics, characterization, and device manufacture are the three essential phases. Numerous physical and chemical methods are being used to create nanomaterials. The new purification and size selection processes may create nanocrystals with clearly defined shapes and structures. Hydrogen is a promising alternative fuel, since it

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