Synthesis Methods and Applications of Cerium Dioxide Nanoparticles: A Brief Review

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***Abstract*: Cerium dioxide (CeO_2) is an oxide of the rare-earth metal cerium and is also referred to as ceric oxide, ceric dioxide, ceria, cerium oxide, and cerium oxide. CeO2 is an n-type semiconductor with a 2.9 eV band gap. It has gained more emphasis because to its great adsorption capacity, stability under radiation, and band characteristics in addition to other factors. The main reasons Cerium Oxide NPs have been used are their distinct surface chemistry, excellent durability, and biocompatibility. Wide-ranging uses for cerium oxide nanoparticles can be found in a variety of industries, including agriculture, medicine, sensors, cells, catalysis, therapies, and drug delivery. The high reactivity and distinctive properties of cerium oxide nanoparticles make them very attractive in the agriculture sector. It is essential to both ecological productivity and food production. Human cells can tolerate cerium oxide nanoparticles both in vitro and in vivo, which enables them for use in medicinal applications. The present review paper provide various brief information of synthesis methods and applications of cerium dioxide.**

***Keywords*: Cerium dioxide, synthesis methods, biocompatibility, nanoparticles, ecological.**

1. Introduction:

Every branch of science and technology has a great interest in nanotechnology, which is currently regarded as one of the top study areas. It has numerous uses in the areas of electronics, communications, business, and medicine [1]. Cerium oxide nanoparticles (CeO_2 NPs), which were synthesized using different methods like chemical, physical and biological have drawn a lot of attention in many scientific and technological domains over the past few years [1, 2]. CeO_2 is a fascinating rare earth metal oxide due to its odd electrical and optical characteristics brought on by the unique 4f electron configuration. The bandgap of CeO_2 is 6.0 eV theoretically, however actual measurements have shown band gaps between 2.76 and 3.19 eV, depending on the cerium precursor and method used for synthesis [3, 4]. Due of the substantial amount of surface oxygen vacancies, CeO_2 is used in the vast majority of applications. In addition to acting as active catalytic sites to bind adsorbates, the oxygen vacancies on the surface of CeO_2 can be used to store and release oxygen with ease [4, 5]. Researchers can either reduce pure CeO_2 in an oxygen-poor environment or add the right kind of dopant elements to enhance the number of oxygen vacancies on the surface of ceria [6, 7]. The first need must be met even when doping increases oxygen vacancies—choosing dopants with the right ionic radii and concentrations is essential. In comparison to bulk ceria, nanocrystalline CeO_2 has a high concentration of defects that are dispersed throughout the surface, grain boundary, and lattice. Many of the physicochemical properties of CeO_2 are strongly influenced by these defects [8, 9]. Doping changes the properties of CeO_2 and these change in properties made variety of applications of CeO_2 in many areas. Hence in the current review paper authors focus on the various synthesis methods and applications of CeO_2 NPs.

2. General properties of Cerium dioxide (CeO_2)

The presence of many oxygen vacancies in cerium dioxide and these vacancies changes variety of physical, chemical, electrical and other properties of cerium dioxide. The general properties of CeO_2 are tabulated in table 1.

Table 1: Properties of cerium dioxide

Sr. No.	Properties	Values and nature
1	Chemical Formula	CeO_2
2	Atomic number	58
3	Appearance	White or pale yellow solid
4	Soluble in water	insoluble
5	Molar mass	172.115 g/mol
6	Density	7.22 g/cm³
7	Melting point	2,400 °C
8	Boiling point	3,500 °C

9	Crystal structure	cubic crystal (Fluorite)
10	Electrical conductance	0.13 Ω^{-1}
11	Specific heat	0.192 J/g K

The crystal structure of the CeO_2 is reveal in figure 1.

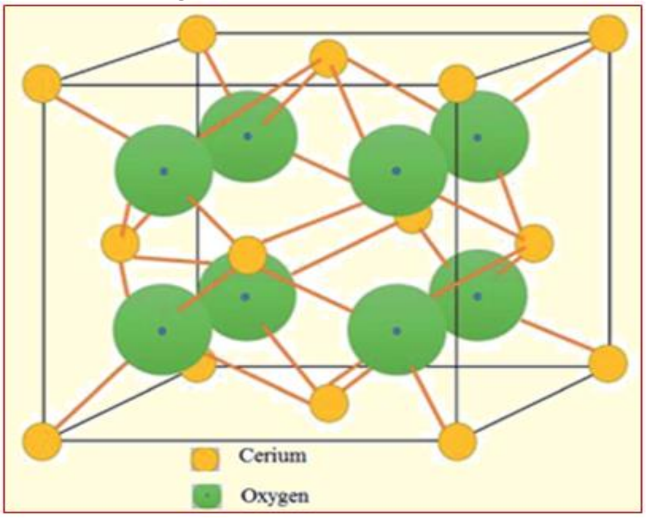

Figure 1: crystal structure of the CeO_2

3. Synthesis methods of Cerium dioxide

Cerium oxide nanoparticles are cost-effective and maintain their catalytic properties under harsh environments. CeO_2 nanoparticles have been synthesized by using a variety of synthesis methods including spray pyrolysis, solvothermal evaporation, precipitation, hydrothermal, chemical bath deposition, microemulsion method, physical vapour deposition, sputtering, thermal oxidation, reversed micelles route, co-precipitation, hydrothermal synthesis, forced hydrolysis, solvo-thermal synthesis, and sol-gel process [10-12]. These methods enable for the production of nanoparticles with high crystallinity, variable particle size, huge surface areas, and small crystallite sizes. CeO_2 NPs have been synthesized in the past utilizing a variety of different methods, as shown in Figure 2.

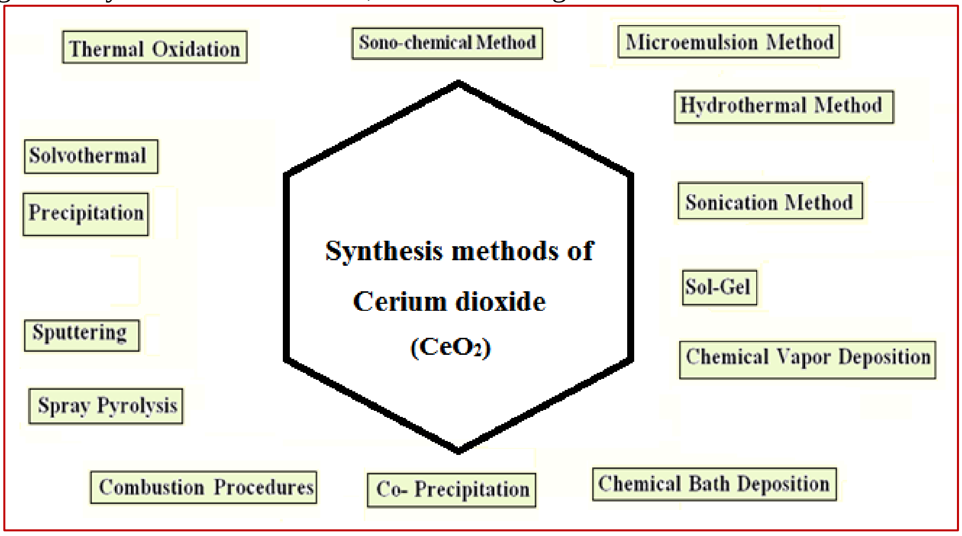

Figure 2: Synthesis methods of the CeO_2

The synthesis of CeO_2 nanoparticles for various applications has been established in research using a variety of methods. The final product can differ depending on the experimental parameters. Consequently, it follows that the resulting nanostructures will have various physical/morphological, chemical, and behavioral characteristics, which will affect each one's behavior. When choosing a method of synthesis, it is essential to take into consideration the intended use of the nanostructures.

The use of natural materials as stabilizing agents in bio-directed CeO_2 NPs production methods has recently grown in significance since it allays concerns about bio-compatibility. These green chemical techniques offer safer ways to make CeO_2 NPs and may be helpful in applications in medicine. In general, these techniques offer less complicated, more affordable alternatives to conventional synthesis techniques. The creation of protein corona for generated CeO_2 NPs in biological fluid environments should be evaluated before drawing any conclusions regarding the biocompatibility of a specific green production technique [11, 12]. The literature review that follows describes numerous ways to make cerium oxide nanoparticles and some of the varied uses for them.

Majumder, D. et al. [13] Developed CO Sensors Using Pristine CeO_2 nanospheres. In the current research work authors used microemulsion method to synthesis CeO_2 nanoparticles. Synthesized nanoparticles of CeO_2 shows mesoporous nature with high surface area. CeO_2 nanospheres with a high porosity and good dispersion were prepared using the reverse micelle precipitation technique. The sensors made of the undoped pure material demonstrated appreciable sensitivity, rapid response and recovery times, and significant selectivity when used for low-concentration (30-10 ppm) CO gas detecting at the ideal working temperature. The prepared sensors have an impressive sensitivity of 43% and a response time of less than 10 s, with a LOD of 10 ppm. The shape, high surface area, and porosity of the materials are well supported by the sensor data.

Liu, Y., et al. [14] In this investigation, huge and polycrystalline CeO_2 nanofibers were synthesized using a simple two-step synthesis process that included electro spinning and calcination, with an average diameter of 376 - 55 nm. In a high-temperature condition, the as-prepared CeO_2 nanofibers exhibit good morphological and structural stability. Additionally, at 800 ºC and 1000 ºC, respectively, CeO_2 nanofibers were used for real-time oxygen (O_2) and carbon monoxide (CO) detection, both of which demonstrated sensitive, reversible, and repeatable response. Depending on the electrical characteristics of the sensing element and the chemical characteristics of the analyte molecules, the gas sensing process of CeO_2 (n- type) nanofibers is described. The electron caught by the Ce lattice and the oxygen vacancy are the two most common point defects in the CeO_2. Authors reported that, the as-prepared CeO_2 nanoparticles have a porous structure with a large surface to volume ratio, and outstanding thermal stability in terms of morphology, chemical structure, and crystalline structure, making them an effective sensing material for CO and O_2 gas sensing in severe conditions. In this study, a promising method for the quick and inexpensive synthesis of a high-temperature stable nanomaterial is shown. This material has a great deal of potential for use in gas sensing in challenging environments.

Pezzini et al. [15] proved that on primary human skin fibroblasts that were subjected to a pro-oxidative assault, the protective effects of CeO_2 NPs. Alfa Aesar supplied monodispersed CeO_2 NPs with a 2 nm average diameter. Following 24 and 72 hours of incubation with CeNPs at concentrations of 0, 100, and 200 g/mL, fibroblast proliferation was evaluated. It was discovered that CeO_2 NPs were internalized, exhibited potent ROS scavenging action, and had no negative effects on the viability of the fibroblasts. Additionally, Ce NPs impacted mitochondrial activity by increasing ATP generation while maintaining the potential of the mitochondrial membrane. This work provides as a proof-of-concept for the use of CeO_2 NPs for a variety of illnesses linked to the build-up of oxidative stress and modification of mitochondrial metabolism.

In an Alzheimer's disease model, Kwon et al. [16] described the design and manufacturing of triphenylphosphonium-conjugated CeO_2 NPs that targeted to mitochondria and prevented neuronal death. Hydrolytic sol-gel processes were used to create CeO_2 NPs. Mitochondrial failure can produce abnormally high quantities of ROS, which ultimately result in the death of neuronal cells. An effective treatment strategy for neurodegenerative illnesses involves targeting CeO_2 NPs to mitochondria. The authors created tiny, positively charged triphenylphosphonium-conjugated CeO_2 NPs that can bind to mitochondria in different cell lines, reduce reactive gliosis, and prevent neuronal mortality. This could represent a cutting-edge tactic in the creation of mitochondrial therapies for Alzheimer's and other neurodegenerative disorders.

According to Kargar et al. [17], a sol-gel approach was used to synthesize tiny cerium oxide NPs that were stabilized with agarose polymers. A semisolid gel that is stable throughout a wide pH range (from 3 to 9) is produced when the temperature is decreased to 35°C to 40°C while heating to temperatures over 90°C. This interpenetrating sol-gel network and nanochannel with 200 nm pore diameters were created as a result of the interpenetrating H-binding between sugar moieties. These nanochannels were utilized to create CeO_2 NPs

CeO_2 NPs with a diameter of 200–300 nm were synthesized by Liu, Y.H. et al. [17] using a precipitation process using ammonia water and oxalic acid as the precipitant, respectively. Several methods, including X-ray, scanning electron microscopy, and FT-IR, were used to characterize the CeO_2 NPs as they had been created. Authors studied the impact of precipitant and calcine temperature on crystal size and shape. The findings demonstrated that the precipitant has a significant impact on the morphology of CeO_2 NPs produced. As the calcine temperature rose, so did the average particle size and crystallite size. In the samples, the nanoparticles had a fluorite-like structure. The easy precipitation approach was used for effectively producing ceria oxide nanoparticles with diameters between 200 and 300 nm in the presence of the different precipitant. According to the current findings, the precipitant has a significant impact on the morphology of the CeO_2 NPs that are produced. XRD was used to determine the structure of the produced CeO_2 NPs. In all of the samples, the nanoparticles have a fluorite-like structure. The average particle size grows as the calcine temperature rises.

4. Applications of Cerium dioxide nanoparticles

CeO_2 NPs has a wide range of applications in different fields, especially biomedical, gas sensor, optical and others [18-25]. The wide range of applications of CeO_2 NPs are shown in Figure 3.

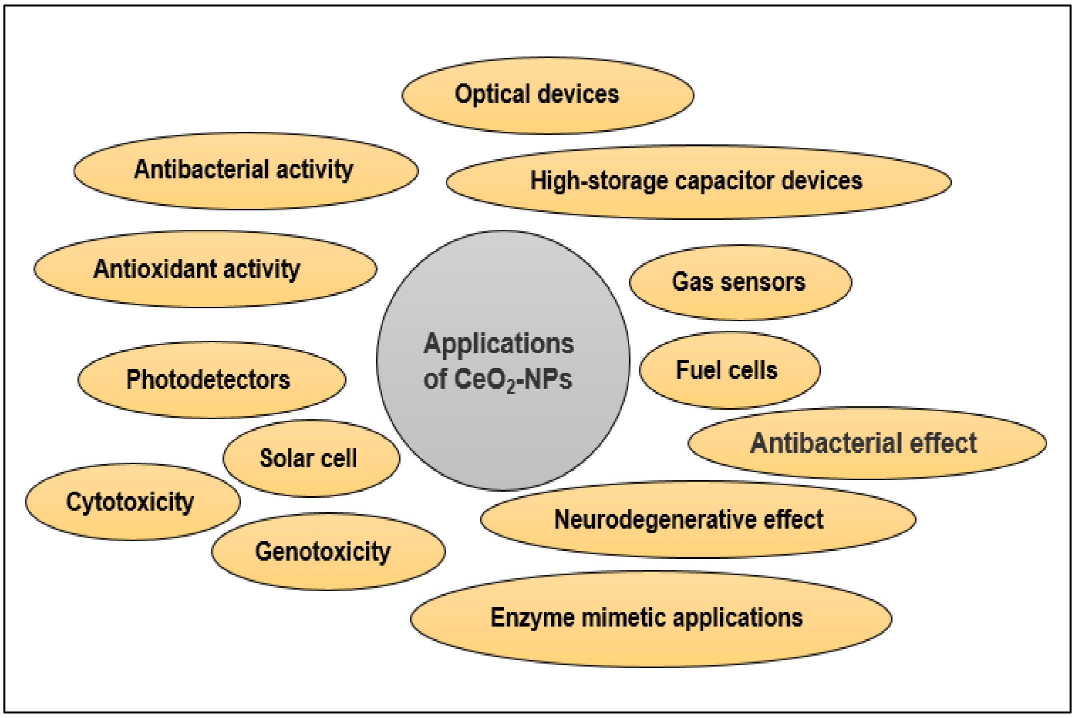

Figure 3: Applications of Cerium dioxide nanoparticles

CONCLUSIONS:

Cerium is a rare earth metal and a member of the lanthanide family. It is the rare earth metal that is most common and exists in two oxidation states. CeO_2 NPs are the most popular commercially available cerium compound used in electronic, gas sensor, biomedical, battery, automobiles and solar cell industries. CeO_2 NPs are becoming more widely used in both industrial and consumer sectors as output rises. Investigators have reported using a wide variety of approaches to synthesis of CeO_2 nanoparticles.

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Conflicts of Interest

The author declare no conflict of interest.

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