Exceptional Encouraged Results in the Characterisation and Applications of Semiconducting CeO<sub>2</sub> and Its Dopant Nanocomposites-A Review

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Abstract

Ceric oxide has been widely investigated because of its multiple applications, such as a catalyst, an electrolyte material of solid oxide fuel cells, a material of high refractive index. Promising results have been obtained using cerium (Ce) oxide nanoparticles (CNPs) as antioxidants in biological systems. Oxide materials, its properties and applications were discussed. Most of the transparent conducting oxides have electrical and optical properties. Many applications were reported by these oxide semiconducting materials.

Keywords: Semiconducting oxides; Characterizations; Applications and devices

Abbreviations: NM: Nanomaterials; AgNW: Silver nano wire; UV: Ultraviolet; TiO<sub>2</sub>: Titanium dioxide; TiO<sub>2</sub>: titanium dioxide; ZnO: Zinc oxide; WO<sub>3</sub>: Tungsten oxide; SnO<sub>2</sub>: Tin oxide

Introduction

Nanomaterials (NM) exhibit novel physicochemical properties that determine their interaction with biological substrates and processes. Three metal oxides nano particles that are currently being produced in high tonnage, TiO<sub>2</sub>, ZnO and CeO<sub>2</sub>, were synthesized by flame spray pyrolysis process and compared in a mechanistic study to elucidate the physicochemical characteristics that determine cellular uptake, sub cellular localization, and toxic effects based on a test paradigm that was originally developed for oxidative stress and cytotoxicity in RAW 264.7 and BEAS-2B cell lines [1]. Silver can be used for the treatment of burns, wounds and several bacterial infections in the form of metallic silver, silver nitrate, silver sulfadiazine. In the anti microbial activity, silver nano material and its nano composites plays vital role. Non-toxic silver nano materials was prepared in a simple and cost effective manner. E.coli bacteria was investigated in luria medium on solid agar plates and these nano particles were exposed to be effective bactericide [2].

Using silver nano particles, a pathogenic bacteria have developed against various antibiotics which have emerged up with assorted medical application such as silver based dressings, silver coated medicinal devices (nano gels, nano lotions etc) [3]. Silver nanowire (AgNW) networks are talented candidates to replace indium-tin-oxide (ITO) as transparent conductors. Highly conductive AgNW composite films with excellent optical transparency and mechanical properties were developed. It showed improved film conductivity and comparable performance to those based on commercial ITO substrates [4]. Titanium dioxide (TiO<sub>2</sub>) displays photocatalytic behavior under near-ultraviolet (UV) illumination and developed new phenomenon "plasmonic photocatalysis". And enhances the degradation of methylene blue dye. The enhancement of the photocatalytic activity increases with a decreased thickness of the SiO<sub>2</sub> shell. The plasmonic photocatalysis will be of use as a high performance photocatalyst in nearly all current applications.
In the review of homogeneous and heterogeneous of CeO$_2$ nanorods, nano flowers, nano cubes and its other different nano structure has attracted much attention due to improvement in its redox properties, transport properties, diffusion, absorption and surface to volume ratio with respect to bulk material. The CeO$_2$ and doping nano composite may also be promising building blocks for nano scale devices. It is one of the most important rare earth oxide material and for its different applications as catalyst [7], oxygen sensor [8], electrolyte, material of solid fuel cell [9], and ultra violet light blocking material [10]. Many recent effort focused on an hierarchical assembly of one dimensional nano scale materials which are expected to have novel collective optical, mechanical, magnetic and electronic properties [11-13]. This significant properties meet out the challenges to purify waste water and degrading pollutants by its free methods of absorption mechanism.CeO$_2$ hierarchical architecture and its composed dopants can be used to control by adjusting the reactant concentration to remove the pollutants from effluent water[0]. A complete understanding of CeO$_2$ nano crystal and its synthesis method provides guidance for the removal mechanism of heavy metals from pollutant water. Because of lack of proper in-situ-method to directly track the growth of nano crystal in solution leads to removal mechanism after their reaction [14]. Ce can exist in two oxidation states; Ce$^{3+}$ (electronic configuration: [Xe] 4f$^1$ and Ce$^{4+}$ (electronic configuration: [Xe]. Therefore, Ce oxide can have two different oxide forms, CeO$_2$ (Ce$^{4+}$) or Ce$_2$O$_3$ (Ce$^{3+}$), in bulk material. At the nanoscale, the Ce oxide lattice has a cubic fluorite structure, and both Ce$^{3+}$ and Ce$^{4+}$ can coexist on the surface. Charge deficiency due to the presence of Ce$^{3+}$ was compensated for by oxygen vacancy in the lattice; therefore, at nanoscale, Ce oxide contains intrinsic oxygen defects. These oxygen defects are actually ‘hot spots’ of catalytic reaction. The concentration of oxygen defects increases with a reduction in particle size [15]. Luminescent properties of CeO$_2$ (Ce$^{3+}$,Ce$^{4+}$) reveals the unusual emission at low wavelength (320nm) coupled with a large Stoke shift ( $\sim$5000cm$^{-1}$) and a high ion lattice coupling strength of $S \sim 30$ which gives an insight into this unusual phenomena of removal mechanism and degrading properties showing some potential for lighting applications [16]. Cerium oxide is a semiconductor has a wide band gap of 3.19 eV [17], much effort has been made to develop potential uses by using this band gap and investigated many applications such as high storage capacitors, conductors, fuel cells, polishing materials and UV-blocks [18]. In oxidation states of Ce(IV) and Ce(III) show strong absorption peak in ultra violet wavelength in range of 232-260nm and 300- 400nm. Materials containing Ce are also Having these properties including increase of optical band gap as a result of a quantum size effect at nano meter.
The resemblance of energy levels of rare earth ion (example Ce) is an important different in emission properties. The difference between the adjacent state is large their energy corresponding to this transition within (4f shell) cannot be transferred to the lattice and it's given out in the form of emission. Sometimes rare earth ions (example Ce) are usually trivalent, this element next to this three tends to exchange electron acquire this stable configuration which will be most suitable for luminescent properties of key energy levels. The energy level may be divided into three classes, those corresponding to 4fn configuration, 4fn-1 configuration, and those corresponding to charge transfer involving the neighbouring ion [15]. Most of the elements exhibit energy transfer luminescence which are activated by sensitizers co-activated. It is important to determine the optimum concentration of other elements with CeO$_2$. Because of obtained efficient luminescence with a minimum energy loss.

The purity of nano composites are the more important issues for Ce ions emissions can be from different two excited states. The way to keep this two emission from the upper states to purify the luminescence to quenches to emission via cross relaxation [16]. Figure 1 shows energy transfer of emission of lattice phonon relaxation intra system energy crossing of Ce$^{3+}$ and Ce$^{4+}$ ions. The efficiency of later process depends upon the magnitude of square overlap integrals between absorption and emission. Coordinate displacement between the equilibrium position of the ground and 5d excited state called the Franck-Condon shift can be adjusted in emission of Cerium by choosing suitable post ions to fix the emission frequency on to increase the emission efficiency. It is worth wide considering that the variation of the energy of one electron in the shell follows the variation of 3+ and 4+ redox potential along the Ce series. It is related to the ability of the trivalent Ce$^{3+}$ to lose (Figure 2).

![Energy transfer of emission of lattice phonon relaxation intra system energy crossing of Ce$^{3+}$ and Ce$^{4+}$ ions.](image)

**Figure 2:** Energy transfer of emission of lattice phonon relaxation intra system energy crossing of Ce$^{3+}$ and Ce$^{4+}$ ions.

One electron and consequently to the stabilisation energy of the Ce$^{4+}$ state which is clearly shown in Figure 2. Like Ce the large band gap material, the energy level of the impurity centre are distributed between valence and conductance band. This is suitable for Ce$^{3+}$ earth ion with discrete atomic states displayed within the large forbidden band gap of materials but the propensity of their Ce ion to give up one electron should be regarded as its hole acceptor capability.

This is the case for Ce$^{3+}$ and Ce$^{4+}$ with one more 4f electron than the empty half shell [17]. Careful analysis of the atomic lattices of Cerium oxide nano particles have clean surface and there is no passivation. But when they are doped with suitable elements the lattices from heterogeneous particles tend to align show they become to contact. Sometimes there is some point defect on the surfaces. Because the synthesis temperature suppose very low and there is not enough energy for the particles to achieve equilibrium shape and size. These type of particles try to attained higher energy than the spherical like particles [18].

**Discussion**

Among these NPs, titanium dioxide (TiO$_2$), a noncombustible and odorless white powder, naturally exists in three modifications (anatase, rutile and brookite). Nowadays, nano-sized TiO$_2$ is produced abundantly and used widely because of its thermodynamic stability, anticorrosion and photocatalysis e.g. as pigments in paints, toothpastes, plastics, paper, ceramics, cosmetics and additives in food (E171) [19,20]. Its use as food...
The material, creating excess negative charge carriers. These

The element Ti consists of five naturally abundant isotopes (46Ti (8.0%), 47Ti (7.3%), 48Ti (7.8%), 49Ti (5.5%) and 50Ti (5.4%). Yet, 46Ti, 48Ti and 50Ti isotopes cannot be used for quantification due to strong isobaric and polyatomic interferences. A preliminary study conducted on the two other Ti isotopes on deionised water and biological samples using different spiked solutions with Ti (2, 5, 10, 20 and 50μg L⁻¹) and different non target elements multi-elemental solution (10, 20, 40, 80 and 160μg L⁻¹ of Li, Al, Cr, V, Ni, Zn, Co, Cu, Ge, Se, Sc, Mn, Fe, Sr, Mo, Y and 0.5, 1 and 5μg L⁻¹ of Ca, K, Mg, Na) showed that 47Ti and show the least interference in biological samples (see supplementary data). 71Ga and 115In were tested as internal standards (IS) and both can be used for this application. So, for the remainder of this study, 47Ti, 49Ti and 71Ga as internal standard (4μg L⁻¹) were used [27].

Functionalized TiO₂ based nanomaterials have positive effects in many biomedical applications such as bone scaffolds, vascular stents, drug delivery systems, and biosensors. For example, nano-TiO₂ scaffolds accelerate the rate of apatite formation and enhance osteoblast adhesion, proliferation, and differentiation [28-31]. Possessing good blood compatibility and anti-coagulation characteristics, TiO₂ nanotube arrays are promising for vascular implants, and nanostructured TiO₂ has been widely reported as drug carriers as well [32,33]. In particular, TiO₂ nanotubes have been shown to be a superior platform for local drug delivery due to their excellent biocompatibility, controllable dimensions, surface chemistry, and large surface-to-volume ratio [34-36]. By changing the nanotube diameter, wall thickness, and length, the release kinetics of specific drugs can be tailored to achieve stable and sustained release [37]. Generally, the requirements for biosensors are good reproducibility and sensitivity to specific chemical and biochemical compounds, and owing to its high sensitivity to glucose, hydrogen peroxide, and cancer cells, nano-TiO₂, has been extensively studied in bio sensing applications, for example, detection of blood glucose in diabetes mellitus patients and early monitoring of cancer [38-40].

The materials chosen as suitable dopants depend on the atomic properties of both the dopant and the material to be doped. In general, dopants that produce the desired controlled changes are classified as either electron acceptors or donors. A donor atom that activates (that is, becomes incorporated into the crystal lattice) donates weakly-bound valence electrons to the material, creating excess negative charge carriers. These weakly-bound electrons can move about in the crystal lattice relatively freely and can facilitate conduction in the presence of an electric field. (The donor atoms introduce some states under, but very close to the conduction band edge. Electrons at these states can be easily excited to the conduction band, becoming free electrons, at room temperature.) Conversely, an activated acceptor produces a hole. Semiconductors doped with donor impurities are called n-type, while those doped with acceptor impurities are known as p-type. The n and p type designations indicate which charge carrier acts as the material’s majority carrier. The opposite carrier is called the minority carrier, which exists due to thermal excitation at a much lower concentration compared to the majority carrier.

Europium doped cerium oxide was synthesised by simple chemical precipitation method to enhance the emission properties and also concentration of oxygen ion vacancy increased with the increase in dopant concentration [41]. Nanocrystalline CeO₂₋ₓ materials, pure or doped with 10%La or 15%Cu, were produced by magnetron sputtering from pure or mixed metal targets, followed by controlled oxidation. The effects of oxide nonstoichiometry and dopants on greater catalytic activity in oxidation reactions and the light-off temperatures for SO₂ reduction by CO, CO oxidation, and methane oxidation and also the differences between the nanocrystalline and the precipitated materials are discussed in terms of the stoichiometry of these oxide catalysts were investigated [42]. The Fe³⁺, La³⁺ and Zr⁴⁺ incorporated in nano CeO₂ lattice prepared by facile co precipitation method and nano-Au/CeO₂ was synthesised by anion adsorption method and the catalytic performance of Au catalysts was investigated [43]. Nanocrystalline homogeneous Cu-doping of CeO₂₋ₓ mixed-metal oxide was developed by magnetron sputtering from a mixed metal target and enhances the catalytic activity [44].

The synthesised nano-sized Ce₀.₉₅Sm₀.₀₅O₁₉₋ₓ particles form core like structures and their crystal size was investigated [45]. Titanium dioxide nanoparticles doped with Fe and Ce prepared by sonochemical method exhibit higher photocatalytic activity as compared to the catalysts prepared by the conventional methods. Also the Ce-doped TiO₂ exhibits maximum photocatalytic activity followed by Fe-doped TiO₂ and the least activity was observed for only TiO₂. The presence of Fe and Ce in the TiO₂ structure results in a significant absorption shift towards the visible region [46]. Ceria nano particles doped with Fe has been investigated for toluene total oxidation reaction [47]. The lattice constant of SnO₂ increases and the grain size decreases with doping of Ni and Ce and gas sensing result revealed that the thick films deposited on alumina substrates using screen printing technique give selectively a high response with fast recovery towards acetone [48].

Thanks to the strength of its Research and Innovation teams, and its expertise in Rare Earths, Solvay has developed separated rare earth polishing products with tightly-controlled
composition, together with specifically designed morphology and characteristics.

In recent years, Ce oxide nanoparticles (CNPs) have gained a lot of interest owing to their regenerative antioxidant property. Ce oxide is a very important material for industrial use, with applications in glass polishing, catalytic convertors for removing toxic gases, solid oxide fuel cells, electrochromic thin-film applications, sensors and catalysts [49].

The responses of cells exposed to nanoparticles have been studied with regard to toxicity, but very little attention has been paid to the possibility that some types of particles can protect cells from various forms of lethal stress. It is shown here that nanoparticles composed of cerium oxide or yttrium oxide protect nerve cells from oxidative stress and that the nerve protection is independent of particle size. The ceria and yttria nanoparticles act as direct antioxidants to limit the amount of reactive oxygen species required to kill the cells. It follows that this group of nanoparticles could be used to modulate oxidative stress in biological systems [50]. Non-stoichiometric oxides are widely used in high temperature energy applications, such as solid oxide fuel cells (SOFCs), oxygen permeation membranes, and gas conversion/reformation catalysis [51-53].

### Biomedical applications

The focus of this review is to reveal a historic prospective of biomedical applications of nanoparticles (NPs) and an overview of the recent developments in this field, and then to discuss the commercialization of nanomaterials. Bones in our body is a nanocomposite material of hydroxyapatite crystallites in the organic matrix and composed of collagen [54].

#### Cancer therapy

Photodynamic cancer therapy is based on the destruction of the cancer cells by laser generated atomic oxygen, which is cytotoxic. A greater quantity of a special dye that is used to generate the atomic oxygen is taken in by the cancer cells when compared with a healthy tissue. Hence, only the cancer cells are destroyed then exposed to a laser radiation. Unfortunately, the remaining dye molecules migrate to the skin and the eyes and can aggregate into larger crystalline structures, depending upon the medium in which they are suspended [59]. Some of the interesting properties of C_{60} include large electro negativity (high electron affinity). Second, crystals of fullerenes have strong photoluminescence (PL), which is sensitive to the exact “inter-ball” spacing, and this spacing is sensitive to the local pH and oxygen content. Third, fullerenes are amenable for chemical modifications which allow for the attachment of organic molecules of interest. Various types of C_{60} functionalization that enhance the hydrophilicity of fullerenes have been described (reviewed in) [57]. Hence, multiple reactive groups and functionalities, including antibodies, drugs, and metals may be attached to the core of C_{60} particles. Fourth, some studies indicate that fullerenes may selectively accumulate in tumors and are reported to be excreted in urine without accumulating in the tissues [60]. Some studies also have reported that fullerenes...
cross and protect the blood brain barrier [61,62], a property that can be exploited for certain applications. Among the various properties of fullerenes, redox properties (electron acceptor-donor) have been extensively studied and are particularly attractive for biomedical applications (Figure 3).

**Carbon nanotubes**

Nanotubes are another type of carbon nanoparticles that have been considered for a variety of biological applications, including as biosensors, drug delivery devices, and as therapeutic agents [63]. Carbon nanotubes are primarily composed of carbon atoms, arranged in benzene rings which form graphene sheets, and are rolled into tubes [64]. The single-walled carbon nanotubes (SWNT) consist of a single layer of graphene sheet, which are characterized by a high ratio of length over diameter (known as the aspect ratio). Thus, SWNTs can be several microns long with a diameter in the range of a few nanometers. Multi-walled nanotubes (MWNTs), on the other hand, consist of several concentric sheets, spaced at less than 1 nm. Nanotubes, because of their distinctive electrical, mechanical, and optical properties, are well suited for several biological applications. For example, nanotubes exhibit outstanding structural flexibility and fluidity and yet possess high mechanical strength. Nanotubes exhibit useful Raman scattering and fluorescence emission in the near infrared (nIR) spectrum between 900 and 1300 nm.

**Quantum dots**

Quantum dots are fluorescent nanoparticles of about 2-10 nm in size. The central core is composed of hundreds to thousands of atoms belonging to the groups of II-VI (e.g., cadmium, selenium) or III-V (e.g., indium) elements. The fluorescence emission spectrum of quantum dots is dependent on the size of the central nanocrystal core which can be adjusted by controlling the amount of precursors during the synthesis. The modest quantum yield of the core nanocrystal is substantially (up to 80%) enhanced by wrapping the core in a zinc sulfide shell. Since the coreshell of the nanocrystal is hydrophobic, it is rendered water soluble with bifunctional molecules (e.g., mercaptohydrocarbonic acid), surface silanization or coating the surface with amphiphilic polymers. The quantum dot crystals are functionalized by linking appropriate targeting molecules through either covalent or non-covalent methods [65].

**Superparamagnetic nanoparticles**

Super paramagnetic nanoparticles contain a magnetically active metal core and are widely used in MRI imaging for enhancing contrast. Iron oxide containing super paramagnetic nanoparticles has been commonly used as the core particle. The size and charge of iron oxide crystals and the nature of chemical coatings are some of the key determinants of the utility of these nanoparticles. Because of the excellent spatial resolution afforded by MRI, iron oxide nanoparticles have been used for diagnostic imaging of tumors, inflammatory and degenerative diseases. Iron oxide particles also have been conjugated to numerous antibodies for targeted molecular and cellular imaging [66].

**Nanotoxicity**

Nanomaterials may gain entry into human systems through inhalation, ingestion, or through dermal routes. Deposition and the physiological consequences elicited by inhaled nanoparticles are dependent on the size, shape (e.g., spherical, fibrous), surface charge, and the aggregation state of the nanoparticles. For example, smaller (<100 nm) particles are likely to travel deeper into the lung and deposit into the alveolar region.

**Detection of Nanomaterials**

It is important to correlate the biological/cytotoxic effects of nanoparticles with the actual intracellular and in vivo quantities that persist upon administration. Whereas a number of techniques, such as electron microscopy or atomic force microscopy, are used to detect nanoparticles in vitro, these techniques may not be suitable or convenient for the routine detection of nanoparticles and their load in tissues. While nanoparticles labeled with radioactivity, fluorescent probes, or chemicals (including drugs, enzymes, biotin, or other reagents) may be readily monitored, it is often difficult to detect low concentrations of unmodified nanoparticles or the metabolites of the conjugated particles. It is also important to consider whether in vivo interactions of nanoparticles (or their
metabolites) with serum proteins or tissues would alter their physicochemical properties, thus, rendering their detection more difficult. Emerging research points to some success in this direction. For example, recent work demonstrates that the intrinsic IR fluorescence may be useful to detect and follow the pharmacokinetics of SWNTs [67]. Similarly, HPLC detection of nanogram quantities of C60 fullerenes from protein containing samples has been reported [68]. In addition, this method might be applicable for the detection of C60 in plasma and skin samples.

Cancer therapy

In most cases, cancer-related deaths occur due to the failure of chemotherapy and/or radiation therapy of the metastatic disease. Therefore, for a successful cancer treatment, it is critical to detect tumors early on during the disease progression, detect and ablate tumor metastasis. Nanotechnology has several applications in improving cancer therapy and some nanosized drugs are currently in clinical trials Brannon-Peppas L [69]. Prominent among those are liposomal doxorubicin and albumin conjugated Paclitaxel, which have been shown to reduce toxicity due to the adverse side effects of respective drugs. Liposomal doxorubicin (Doxil) has been shown to be an effective anti-neoplastic agent with improved biodistribution (longer plasma circulation times) which reduces severe dose-limiting cardiotoxicity associated with the drug treatment [70]. Like many drugs, Paclitaxel is poorly soluble in water and is administered as a formulation with Cremophor EL (polyethoxylated castor oil) and causes side effects such as hypersensitivity and nephrotoxicity and neurotoxicity. While several different formulations have been made to minimize the toxic effects of this drug, albumin-conjugated nano-sized paclitaxel (Abraxane), a Cremophor free-formulation, has been shown to be well-tolerated and yet more effective than the conventional drug [71]. Additionally, a number of nanosized formulations of other chemotherapeutic drugs such as 5-fluorouracil and camptothecin are being tested. Further, nanomaterials are suitable for drug-eluting implants and their drug delivery properties spur potential applications in the biomedical field [79]. Antibacterial Agent Delivery

Carrier of inorganic antimicrobial agents

The antibacterial properties of Zn-doped TiO2 nanomaterials have also been investigated in recent years [80]. Zn-doped Ti-based nanofibers promote antimicrobial effects against Staphylococcus aureus and Escherichia coli due to cell membrane disruption and cytoplasm leakage. The antibacterial activity of ZnCl2/TiO2, Zn(NO3)2/TiO2, and ZnSO4/TiO2 follows the subsequent order: ZnSO4 > ZnCl2 > Zn(NO3)2 > Zn(NO2)2, and the highest antibacterial activity observed for ZnSO4/TiO2 is possibly ascribed to the improved surface acidity [81]. It has also been reported that zinc can be incorporated into TiO2 coatings to achieve a good bacterial inhibition ability, and the better antibacterial activity of Zn-incorporated TiO2 coatings may be attributed to the fact that Zn ions can be slowly and constantly released from the coatings [82,83].

Biosensors

A biosensor is a device incorporating a biological sensing element either closely connected to or integrated into a transducer. Specific molecular recognition is a fundamental prerequisite on the basis of the affinity between complementary structures such as enzyme-substrate, antibody-antigen, and receptor-hormone, and this property is often used to generate the concentration dependent signals. The sensitivity and specificity depend on the biological recognition system [83,84]. Since the development
of enzyme-based sensors for glucose by Clark and Lyons [85], improvements have been made in terms of the sensitivity, selectivity, and reproducibility as a result of rapid developments in nanotechnology and nanomaterials. Nanomaterial-based biosensors, which represent the integration of materials science, molecular engineering, chemistry, and biotechnology, improve the sensitivity and specificity of biomolecule detection and have great potential in biomolecule recognition and pathogenic diagnosis [86, 87].

In order to improve the performance of biosensors, TiO$_2$ nanomaterials such as nanoparticles [88], nanotubes [89-90], nanofibers [91], HaoTang, gold nanoparticle encapsulated TiO$_2$ nanoclusters [92], and TiO$_2$/SiO$_2$ nanocomposites [93,94], have been used in biosensing devices for enzymes, antibodies, microorganisms, and DNA. Nanostructured TiO$_2$ based biosensors are sensitive, selective, fast, and reproducible for the detection of various chemical and biochemical compounds such as glucose, hydrogen peroxide, and cancer cells because of their superior properties including nontoxicity, large surface area, high adsorptivity, good uniformity, and excellent biocompatibility. In fact, TiO$_2$ based biosensors have been proposed to be a prospective interface for the immobilization of biomolecules [95,96].

**Enzymatic TiO$_2$ based biosensors**

Various types of enzymes such as glucose oxidase (GOD), horseradish peroxidase (HRP), urease, cytochrome C (cyt.c), and glutamate dehydrogenase can be immobilized on TiO$_2$ nanomaterials [97]. When the two enzymes GOD and HRP are co-immobilized on the TiO$_2$ based nanostructured surfaces, direct electron transfer between enzyme and electrodes is significantly enhanced due to the nanostructured environment of the TiO$_2$ based layers [98-103]. These biosensors have a good sensitivity, low detection limit (≈10-6 M), and fast time response (few seconds) making them promising in low-cost, miniaturized multi-functional biosensors. In biosensing applications, novel nanostructures that can immobilize more enzymes on the surface of TiO$_2$ and accelerate electron transfer between the biological components and electrode continue to be researched extensively.

**Conclusion**

CeO$_2$ and its dopant semiconducting oxides were used for the various applications of nanocomposites. The properties of the materials were varied due to its doping ratio of the oxide materials. Some fundamental physical and chemical properties of ceria and its dopants were addressed by the many researchers and their recent progress in the size and shape-controlled synthesis and morphology-dependant performance of ceria and its doped oxide materials nano-microstructures was highlighted. Although, the nanostructures, morphologies, characterization approaches and many applications studies such as photocatalysts degradation processes of ceria-based nanostructured materials are extensively investigated in recent years so their properties and its applications with the achievement of some exceptional encouraged results were reported here.

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