Structural and Optical Properties of Mesoporous Sm$^{3+}$: CeO$_2$ and Its Environmental Applications

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ABSTRACT

Cerium oxide (CeO$_2$) is one of the most interesting oxides industrially because it has been widely used as a catalyst, three-way automotive catalytic converters for purification of exhaust gases, oxygen sensors, and so forth for long periods of time. Recently, CeO$_2$ nanoparticles has also emerged as a fascinating and lucrative material for environmental remediation applications. The key for most of the above mentioned applications of CeO$_2$ based materials is its extraordinary ability to release or uptake oxygen by shifting some Ce$^{4+}$ to Ce$^{3+}$ ions. Better catalytic performances of CeO$_2$ have been reported in the presence of Ce$^{3+}$ and oxygen vacancy defects, which are potentially potent surface sites for catalysis. Here, we present the effect of Sm$^{3+}$ doping on structural and optical properties of mesoporous CeO$_2$ and its environmental applications. The XRD results showed that even as-prepared material has cubic fluorite structure of CeO$_2$ with no crystalline impurity phase. All the nanopowders exhibited strong absorption in the UV region and good transmittance in the visible region. Mesoporous Sm$^{3+}$ doped CeO$_2$ sample could effectively photodegrade all types of cationic, anionic and nonionic dyes under natural sunlight irradiation. These high surface area mesoporous materials exhibited notable adsorption and effective removal of Cr(VI) from aqueous solutions. Further Sm$^{3+}$ doping was found to cause unusual emissions with a dominant $^4$G$_{5/2} \rightarrow ^6$H$_{5/2}$ transition centered at 573 nm. Additionally, the luminescence intensities enhanced with increasing Sm$^{3+}$ concentration from 0.5 mol% to 1 mol% with further increasing Sm$^{3+}$ concentration leads to the decrease in luminescence intensities. The presence of increased surface hydroxyl group, mesoporosity, and surface defects have contributed towards an improved activity of mesoporous CeO$_2$, which appears to be potential candidates for optical, and environmental applications.
Motivation

In recent years, inorganic phosphors find their applications in cathode ray tubes (CRT), field emission devices (FED) and fluorescence applications. Rare earth doped oxide nanoparticles serve as the best phosphor material in comparison with other inorganic metal oxide nanomaterials. Among the rare earth family, cerium (Ce) is the most abundant element. With a high abundance and various unique properties nanstructured ceria (CeO₂) has attracted much attention for a wide variety of technological applications as in the area of three-way catalysts (TWCs), fuel cells, solar cell, phosphors, UV absorber/blocker, shielding material, and in sunscreen cosmetics, hydrogen storage materials, developing new luminescence devices.

Objectives

- Development of pure and rare earth doped ceria nanopowder via facile and low cost method by using inorganic precursors.
- Convenient low temperature preparation of multifunctional efficient CeO₂ materials with higher surface area and higher crystallinity.
- Development of highly luminescent materials.
- Structural and optical characterization by using TG-DSC, XRD, BET, XPS, UV-visible, PL, FESEM and HRTEM analysis.
- Application of synthesized nanopowder in the for removal of toxic heavy metal Cr(VI) by adsorption.
- We also demonstrate a new photochemical remediation method for dye-polluted waters by using samarium doped ceria nanoparticles and natural sunlight only.

Synthesis

\[\text{SMA} + \text{CeO}_2 + \text{dilute HNO}_3 \rightarrow \text{SMA-CeO}_2 \]

Mixture with stirring

\[\text{SMA-CeO}_2 \text{solution} \]

SMA-CeO₂ solution

SMA - CeO₂ /Ce²⁺ solution

IDS

SB₂O₅

Power

Fluorescent microscope images

\(\lambda = 350 \text{ nm}\)

\(\lambda = 532 \text{ nm}\)

Conclusions

- Multifunctional rare earth doped CeO₂ mesoporous materials with high crystallinity and high surface area have been successfully synthesized by a facile and low-cost method.
- Structural, spectroscopic, and electron microscopy techniques were used to characterize the prepared materials.
- The resultant Sm³⁺ doped CeO₂ exhibits excellent photocatalytic activities for degradation of toxic organic pollutant under natural sunlight irradiation in absence of any oxidising agents and over a broad range of pH values.
- CeO₂ : Sm³⁺ material having strong UV-visible absorption, and PL will have important applications in catalysis, and separation technology, and the possibility of these materials to be used as better UV blockers and nanoscale photoluminescent or nano-optoelectronic materials.

Publications