Review on: Synthesis Approaches and Applications of Lanthanum Oxide Nanoparticles

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Abstract: The current research paper presents the different synthesis approaches of lanthanum oxide (La_2O_3) and its applications in the field of sensors. Due to its superior structural stability at high temperatures, active surface sites, chemical, and optical properties with substantially influenced luminescence efficiency in the visible domain, Rare Earth Metal Oxide Semiconductors (REMOS) have seen an increase in demand in recent years. The excellent qualities of such materials have increased their use in the fields of technology, industrial, pollution prevention, and, in particular, the manufacture of sensors. La_2O_3 is one of the rare earth metal oxide semiconductors with the widest energy band gap (Eg= 4.3 eV) and lowest lattice energy, making it potentially more useful for a wide range of optical and electrical applications. In past decades, a large amount of research has been conducted on these materials to evaluate potential applications in the optical, electrical, optoelectronic, electronic, gas sensing and biological areas. The size, shape, and surface of the lanthanum oxide have a critical role in the response and performance of the devices in these applications, among other things. The future of La_2O_3 as a key material in modern research is also discussed.

Keywords - *Lanthanum oxide, lattice energy, gas sensing, optical and electrical.*

I. Introduction:

One of the most researched categories of gas sensors is rare earth metal oxide semiconductor gas sensors. Due to their low cost and flexibility in production, simplicity of usage, and vast number of detectable gases/possible application areas, they have gained a lot of attention in the field of gas sensing under atmospheric circumstances. The detection of this reaction can be done by detecting the change in capacitance, work function, mass, optical properties, or reaction energy released by the gas/solid contact, in addition to the conductivity change of the gas-sensing material [1]. The reversible reaction of the gas with the material's surface has been demonstrated by numerous researchers to be a feature of conductometric semiconducting metal oxide gas sensors. Internal and external causes, such as natural qualities of base materials, surface areas and microstructure of sensor layers, surface additives, temperature and humidity can all influence this response [1, 2]. The sensing responses of several types of pure and prepared semiconducting materials to various hazardous and greenhouse gases have been determined to be good to exceptional [3]. The primary goal of using various materials to sense these gases is to find the best sensing material at a given temperature. Gas sensors are very useful for pollution control, preventing industrial hazards, preventing gas leakage, and ensuring that the environment is free of harmful and toxic gases [4].

A variety of metal oxides can be employed to conduct measurements in order to detect flammable, reducing, or oxidizing gases. Metal oxide semiconductor materials, which are inexpensive and available in large quantities, are the most commonly, recognized gas sensors today. The two most common types of semiconducting metal oxide sensors are n-type and p-type. N-type sensors have an electron as the majority carrier, while p-type sensors have a hole as the majority carrier [5, 6]. La_2O_3 is a great p-type semiconducting material that can be used in a variety of applications. The chemistry of lanthanum compounds and their applications in organic synthesis have evolved considerably in recent years. First and foremost, they are appealing for use in organic transformations and other vital applications due to their moderate price and low toxicity. The utilisation of lanthanide (III) compounds as catalysts in organic synthesis has piqued the interest of a slew of scientists. Lanthanum oxide is white and odourless. It is water insoluble but soluble in dilute acid. Photo - electric conversion efficiency of lanthanum oxide nanoparticles is excellent. La_2O_3 is a low-cost basic material that can be used in a wide range of organic reactions. La_2O_3 is a non-toxic material that is utilised in a variety of applications including gas sensors, catalysts, supercapacitors, batteries, optoelectronic, luminescence, electromagnetic, and biomedicine [7, 8]. Because of the required shapes and sizes of the nanoparticles, nanotechnology allows for a plethora of beautiful applications (NPs). However, due to the limited study of synthesis and characterization of rare earth metals, they are more fascinating to choose for further research. Lanthanum oxide nanoparticles (La_2O_3 NPs) are an excellent choice for research due to their fantastic applications.

II. Synthesis approaches of Lanthanum Oxide:

La_2O_3 nanoparticles were previously synthesised using a variety of approaches shown in figure 1. The approaches including sol-gel, spray pyrolysis, solvothermal, thermal decomposition method, precipitation, co-precipitation, hydrothermal, Chemical Bath Deposition, Reflux method, Solution combustion, microemulsion method, chemical vapor deposition, sputtering, thermal oxidation, and combustion procedures. Using these approaches the high crystallisation degree, pure phase, and adjustable particle size or nano powders or nanoparticles can be synthesized.

Ramjeyanthi, N. et. al. [9] synthesized successfully the nanoparticles of La_2O_3 by using precipitation method and studied their structural and optical properties. In this work, lanthanum nitrate hexahydrate ($La(NO_3)_3.6H_2O$) as a precursor and sodium hydroxide (NaOH) can act as a precipitating agent. The characterization study was performed by using physical, chemical, morphological and optical characteristics of obtained La_2O_3 nanoparticles were characterized by using the XRD, SEM, FTIR, UV-Visible DRS and PL analytical tools respectively. Author reported the hexagonal structured La_2O_3 nanoparticles with slight mixed state of lanthanum hydroxide and carbonates were confirmed from XRD pattern and crystallite size of the particles is found to be 41 nm by using Scherrer formula and 47 nm by using W-H Plot. The SEM image of La_2O_3 nanoparticles shows that the particles are spherical in shape with some agglomerations. FTIR results were confirmed the presence of La_2O_3 from the metal-oxygen stretching band at 865, 727 and 635 cm-1. The high energy indirect band gap of 5.35 eV was obtained from KM plot using DRS reflection spectra, which indicate the La2O3 have good optical response. The PL spectrum indicates the La_2O_3 nanoparticles having violet-blue-red emissions and the results also confirm the reduction in the recombination rate of electron-hole pairs due to the oxygen vacancies.

Nowicki, W. et. al. [10] synthesized nanoparticles of La_2O_3/ SiO_2 by using sol-gel method. Author were studied the textural and structural properties of crystalline La_2O_3/ SiO_2 oxides system prepared by non-aqueous sol–gel method. The use of only three reactionary components permits obtaining simple sol–gel reaction system and allows the synthesis of organic-inorganic materials with new properties from ingredients insoluble in polar medium. Author reported the XRD patterns verified the imperfectness of hexagonal structure of lanthanum oxide during growth of crystals at amorphous silicon dioxide investigated in this work. An increase in the number of defects was noted with increasing silicon dioxide concentration in the studied system. The addition of amorphous SiO_2 improves the textural properties of the gel surface. FTIR spectra data confirmed a decrease in the basic character of lanthanum oxide with increasing Si incorporation into the gel, which leads to a change in the hydrolytic properties of modified materials.

Sulaiman, N. et. al. [11] prepared La_2O_3 nanoparticles by sol-gel technique. In this technique, La $(NO_3)_3.6H_2O$ is used as source of Lanthanum oxide as a precursor and PALE biomaterial. Author introduced a new eco-friendly method, safe and harmless, for synthesis of Lanthanum oxide nanoparticles using Physalis angulata leaf extract (PALE). The secondary metabolites in PALE act as weak base source and stabilizing agent in La_2O_3 nanoparticles formation. Authors reported the formation of La_2O_3 was characterized through FTIR spectrum of La-O vibration at 400 and 454 cm^{-1}. Crystallinity of La_2O_3 nanoparticles was measured using XRD. The band gap value of La_2O_3 nanoparticles was 5.39 eV. SEM image showed the agglomerated nanoparticles with elements composition of La and O as La_2O_3. The shape and single particle size of La_2O_3 nanoparticles measured using TEM were spherical shape with size in the range of 25-50 nm.

Kale, S.S. et. al. [12] prepared thin films of La_2O_3 by using a simple and inexpensive spray pyrolysis method. The films were prepared by spraying 0.1 M lanthanum chloride solution onto the conducting and non-conducting glass substrates. The substrate temperature was varied from 523 to 723 K and structural, optical and electrical properties of the films were studied. The prepared thin films of La_2O_3 were employed as a photoelectrode and formed photoelectrochemical (PEC) cell.

Saravani, H. et. al. [13] synthesized nanoparticles of transition metal oxides like $La_2C_2O_5$ and La_2O_3. The prepared compound was calcined at different temperature ranges and studied their structural characterization by using Fourier transform infrared (FT-IR), Ultra Violet-Visible (UV-vis) spectroscopy and cyclic voltammetry (CV) method for electrochemical studies. Author reported La_2O_3 have spherical shape with porous surface and particle size 24.56- 13.40nm. The X-ray diffraction patterns at room temperature revealed that, highly pure and crystallized Lanthanum oxide nanoparticles as $La_2C_2O_5$ and La_2O_3 formula with orthorhombic phases in 600°C and 900°C respectively, with an average particle size of about less than 100nm for both nano-oxides. SEM figure show that the particles have same morphology with a uniform porous surface.

He, Y.W. et. al. [14] synthesized La_2O_3/Graphene oxide (GO) nanocomposites using $LaCl_3 \cdot 7H_2O$ and multilayer GO as a source material and DMF without extra stabilizer in one step method were used. Prepared products were characterized by SEM, TEM, and XPS. Sonication was performed on Shen Zhen JieMeng JP-010T ultrasonic cleaner with a frequency of 40 KHz and a nominal power of 100 W. Authors were studied dye degradation properties of synthesized La_2O_3/graphene oxide (GO) nanocomposites.

Bahari, A. et. al. [15] synthesized La_2O_3 and CrO_2 at low temperature using sol-gel method. Lanthanum dioxide was prepared by the hydrolysis and condensation of $LaCl_3$ used as precursor under acidic conditions. In this process, a 0.1 M solution of $LaCl_3$ is sprayed onto a preheated substrate. Author reported hexagonal La_2O_3 and cubic CrO_2 phases from obtained XRD patterns.

Zhang, Q.L. et. al. [16] synthesized La_2O_3 nanoparticles by using simple and less expensive precipitation method. He also studied the effects of reactant concentration, precipitator and dispersant agent on properties of Lanthanum oxide particles. Prepared nanoparticles of La_2O_3 were characterized by XRD and SEM. Author reported the average particles size of Lanthanum oxide powders with spherical shape gained was about 188 nm.

Pathan, A.A. et. al. [17] synthesized La_2O_3 nanoparticles by using solution combustion method. Author reported from XRD the peaks are observed at 24.32˚, 31.90˚, 36.38˚, 47.71˚ and 56.79˚ respectively corresponding to the (h k l) values of the peaks (1 0 0), (1 1 0), (1 1 0), (2 0 0) and (2 1 0) respectively. The lattice parameters were in good agreement with JCPDS card number 04 - 0856, having lattice parameters a = b = c = 3.6180 Å and $\alpha = \beta = \gamma = 90^{\circ}$ and the average crystallite sizes of samples synthesized by this method is 42 nm for $\psi = 1$. From FTIR, identify the presence of La_2O_3. From FTIR analysis, it shows good formation of La_2O_3 NPS for La-O band at 653 cm^{-1} and TGA/DSC reveal the effective weight loss of materials at 350˚C and exothermic peak of La_2O_3 at 800˚C. Structural properties were examined by SEM reveals porous and porosity was good in network of Nano crystalline La_2O_3. The EDAX shows the purity and percentage of the La_2O_3 nanoparticles. From TEM analysis, author reported the samples particles not good in crystal due to severe agglomeration.

Karthikeyan, S. et. al. [17] synthesized La_2O_3 nanoparticles by a simple reflux method. As-prepared and calcinated the La_2O_3 nanoparticles were used to study. The as-prepared and calcinations products were characterized by X-ray diffraction (XRD), Scanning electron microscopy (SEM), Fourier transform infrared (FT-IR), Band gap was calculated by UV visible spectroscopy. Morphological studies revealed the thickness of the as-prepared La_2O_3 nanoplate's particle size 50nm and on calcinated the plate like structure break into smaller La_2O_3 nanoparticles. The optical band gap being greater then 5eV for both the samples such that the prepared La_2O_3 structure may be used for MOSFET application.

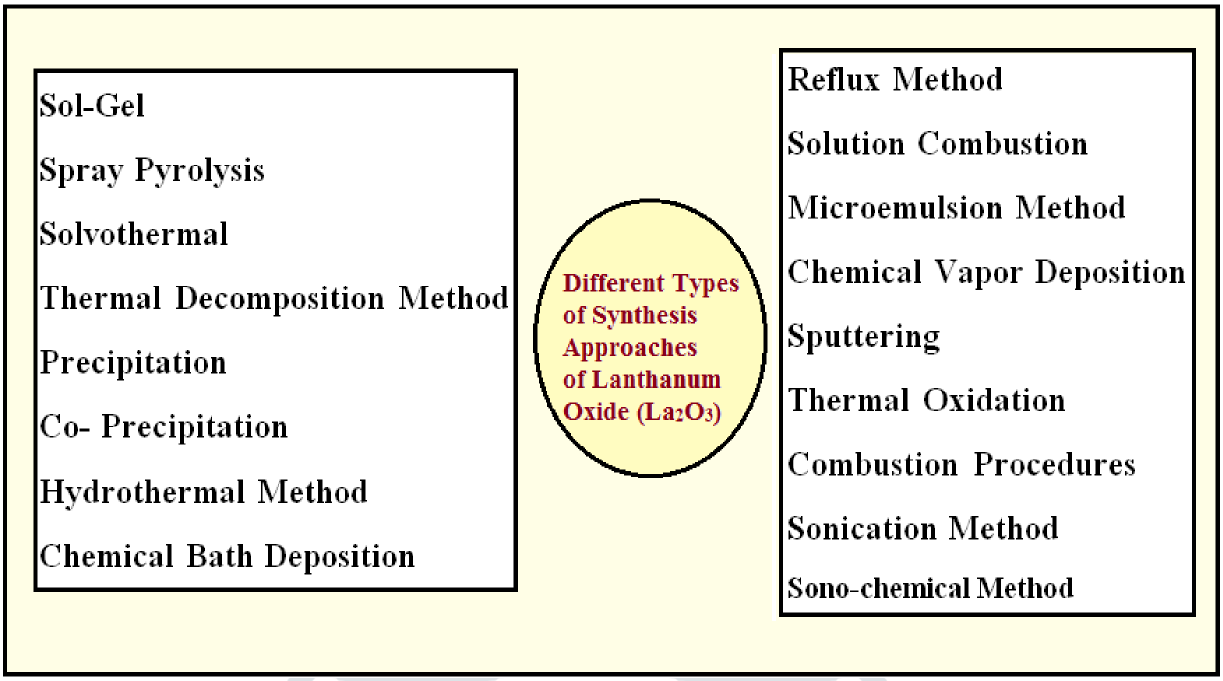

Figure 1: Different approaches of synthesis of lanthanum oxide

III. Applications of Lanthanum Oxide nanoparticles (NPs):

Ehsani, M. et. al. [19] fabricated Pt /La_2O_3 /SnO_2 thick films on alumina (Al_2O_3) substrate by using simple screen-printing technique and prepared films were used as Carbon dioxide (CO_2) gas sensor. The functional sensitive material was prepared by La_2O_3 /SnO_2 nano powder and the addition of 1 wt.% and 3 wt.% Platinum (Pt) using high-speed ball milling method. Pt/ La_2O_3 /SnO_2 thick film shows a high sensitivity to the increasing CO_2 gas concentration at 225 °C in air atmosphere.

Bakiz, B. et. al. [20] investigated the carbonatation of La_2O_3 oxide and the decarbonization of Lanthanum Carbonate phase $La_2O_2CO_3$ using thermal and thermogravimetry analyses under CO_2 gas flow. The carbonation kinetics of La_2O_3 has been determined at various temperatures. Authors reported the phase modifications associated with high ionic conduction might be used as electrical sensitive material to detect CO_2, provide temperatures that could be fixed close to 400–550°C.

Shafiei, M. et. al. [21] reported the electrical and hydrogen sensing properties of a novel Schottky diode based on a nanostructured Lanthanum oxide-molybdenum oxide compound. Molybdenum oxide nanoplatelets were grown on SiC substrates via thermal evaporation which was then subsequently coated with lanthanum oxide (La2O3) by RF sputtering. The fabricated thin layers were used to detect hydrogen gas. Authors reported that the presence of a La_2O_3 thin layer substantially improves the hydrogen sensitivity of the MoO3 nanoplatelets.

Balusamy, B. et. al. [22] studied demonstrated the acute toxicity of Lanthanum oxide nanoparticles on two sentinel aquatic species, fresh-water microalgae Chlorella sp. and the crustacean Daphnia magna. This study proved to be beneficial in understanding acute toxicity in order to provide environmental protection as part of risk assessment strategies.

Table 1: Synthesis Approach and Applications of Lanthanum Oxide Nanoparticles

Sr. No.	Material	Synthesis Approach	Application	References
1	Lanthanum Oxide (La_2O_3)	Sputtering	The moisture absorption degrades the permittivity	23
2	Lanthanum Aluminum Oxide	Atomic layer deposition	Finding permittivity	24
3	La_2O_3	Coprecipitation method	CO gas sensor	25
4	La_2O_3	Hydrolysis reaction	Microwave Absorber	26
5	La_2O_3	Homogeneous precipitation process	Antibacterial activity	27
6	La_2O_3 Composites	Ball milling method	Mechanical properties	28
7	Lanthanum Oxide	Co-Precipitation Method	Optical	09
8	La_2O_3	Solution blending	Structural and physical properties	29
9	La_2O_3	Dual plasma deposition	Hemocompatibility and antibacterial properties	30
10	La_2O_3	Pechini Method	CMOS applications	31
11	La_2O_3	Spray pyrolysis method	Supercapacitor and gas sensor	32
12	La_2O_3	Coprecipitation method	Acetone sensor	33
13	La_2O_3	Ultrasonic spray pyrolysis	CO_2 gas sensor	34

IV. Conclusion:

This review article provides basics of the Lanthanum Oxide (La_2O_3). The various applications of La_2O_3 nanomaterials in the catalysis, fuel cells, photovoltaic, optics, biomedical, gas sensing and other. We have also discussed different type's synthesis approaches for the synthesis of lanthanum oxide nanoparticles.

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