Synthesis Methods and Applications of $LaCrO_3$ Nanoparticles: A Short Review

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Abstract

In the twenty-first century, nanotechnology emerged as a scientific accomplishment. This field encompasses multiple disciplines and deals with the synthesis, dealing with, and use of materials smaller than 100 nm. Numerous industries, including the environment, food production, agriculture, biotechnology, healthcare, and pharmaceuticals, have substantial uses for nanoparticles. Lanthanum chromite ($LaCrO_3$) nanoparticles are of significant interest due to their unique properties and potential applications in various fields. $LaCrO_3$ nanoparticles are synthesized via various methods like sol-gel, hydrothermal, chemical, physical and co-precipitation, exhibiting interesting optical, electronic and catalytic properties that enable applications in energy storage, catalysis and environmental remediation. Ongoing research aims to further optimize the synthesis and performance of these nanoparticles. The present research work is focus on the elaborate various synthesis methods and applications of $LaCrO_3$ nanoparticles in brief.

Keywords: Nanotechnology, Lanthanum Chromite, Synthesis, Agriculture, Hydrothermal

1. Introduction:

A prime example of an emerging technology is nanotechnology, which offers designed nanomaterials with enormous potential for creating goods with significantly better performance [1, 2]. Nowadays, nanoparticles are used in electronic devices, skincare products, sports equipment, sensors, energy-storage equipment, and cleaning up the environment. Nanotechnology is a rapidly advancing field that deals with the manipulation and control of matter on an atomic and molecular scale, typically below 100 nanometers. The need for nanotechnology arises from its potential to revolutionize various industries and address some of the most pressing challenges facing humanity. When scientific advancements like the development of the scanning tunneling microscope in 1981 and the identification of fullerenes in 1985 with their elucidation came together, nanotechnology was born in the 1980s. Nanotechnology is essential for driving innovation across a wide range of fields [2, 3]. Its ability to manipulate matter at the nanoscale opens up new possibilities for solving complex problems, enhancing the quality of life, and contributing to sustainable development. As research and development in nanotechnology continue to advance, its impact is expected to grow, leading to even more ground breaking applications and solutions [2-4].

The synthesis of nanoparticles is essential due to their unique properties and vast potential applications that cannot be achieved with bulk materials [5]. The synthesis of nanoparticles is crucial for exploiting their unique properties and achieving breakthroughs across numerous fields [5, 6]. Their small size and high surface area enable enhanced performance and functionality in medical, environmental, energy, industrial, and electronic applications. The continued development and refinement of nanoparticle synthesis methods are essential for advancing technology and addressing global challenges [6, 7]. For the synthesis of NPs, there are primarily three different types of methods: chemical, biological, and physical approaches. It is also known as the top-down strategy for the physical method and the bottom-up approach for the chemical and biological techniques together [8-10].

$LaCrO_3$ is a perovskite oxide with a range of interesting physical, chemical, and electrical properties that make it useful for various applications, particularly in high-temperature and catalytic environments. $LaCrO_3$ has a perovskite crystal structure (ABO_3), where La (Lanthanum) occupies the A-site, Cr (Chromium) occupies the B-site, and O (Oxygen) forms the octahedral network [11, 12]. The theoretical density of $LaCrO_3$ is approximately 6.67 g/cm^3. It exhibits good mechanical strength and hardness, which are important for structural applications. $LaCrO_3$ is act as a catalyst in various chemical reactions, including oxidation and reduction processes. Its catalytic activity can be modified by doping with other elements [13, 14]. It is resistant to corrosion and chemical attack, enhancing its durability in various environments. $LaCrO_3$ exhibits mixed ionic and electronic conductivity. It is an intrinsic p-type semiconductor at high temperatures, which makes it useful as a cathode material in solid oxide fuel cells. The band gap of $LaCrO_3$ is around 3.4 eV, which contributes to its semiconducting behavior [14, 15]. It has interesting dielectric properties, with a high dielectric constant, making it useful in capacitor applications and as a dielectric material in electronics. $LaCrO_3$ exhibits moderate thermoelectric properties, which can be enhanced by doping with other elements to improve its performance in thermoelectric devices. $LaCrO_3$ is a versatile material with a unique combination of physical, chemical, and electrical properties. Its high thermal stability, chemical resistance, and electrical conductivity make it suitable for a wide range of advanced technological applications, particularly in high-temperature environments and energy-related devices [15-18]. Research continues to explore and enhance these properties, expanding the potential applications of $LaCrO_3$ nanoparticles.

In the present review article, we discussed the various synthesis methods for synthesis of $LaCrO_3$ nanoparticles and the different applications of $LaCrO_3$ nanoparticles.

2. Synthesis methods for $LaCrO_3$ nanoparticles:

The synthesis of $LaCrO_3$ nanoparticles is achieved through various methods, each with its own advantages and specific conditions. Each synthesis method for $LaCrO_3$ nanoparticles has its own set of advantages and is chosen based on the desired properties of the final product and the specific application requirements. The sol-gel method and hydrothermal synthesis are particularly noted for producing high-purity, well-controlled nanoparticles, while methods like solid-state reaction and co-precipitation are more straightforward and scalable.

2.1 Sol-gel

The Sol-Gel method is a popular technique for synthesizing $LaCrO_3$ nanoparticles due to its ability to produce materials with high purity, homogeneity, and controlled particle size. The advantageous of sol gel method are produce high purity and homogeneity.

Fig. 1 shows the general steps for synthesis of $LaCrO_3$ nanoparticles by sol gel method.

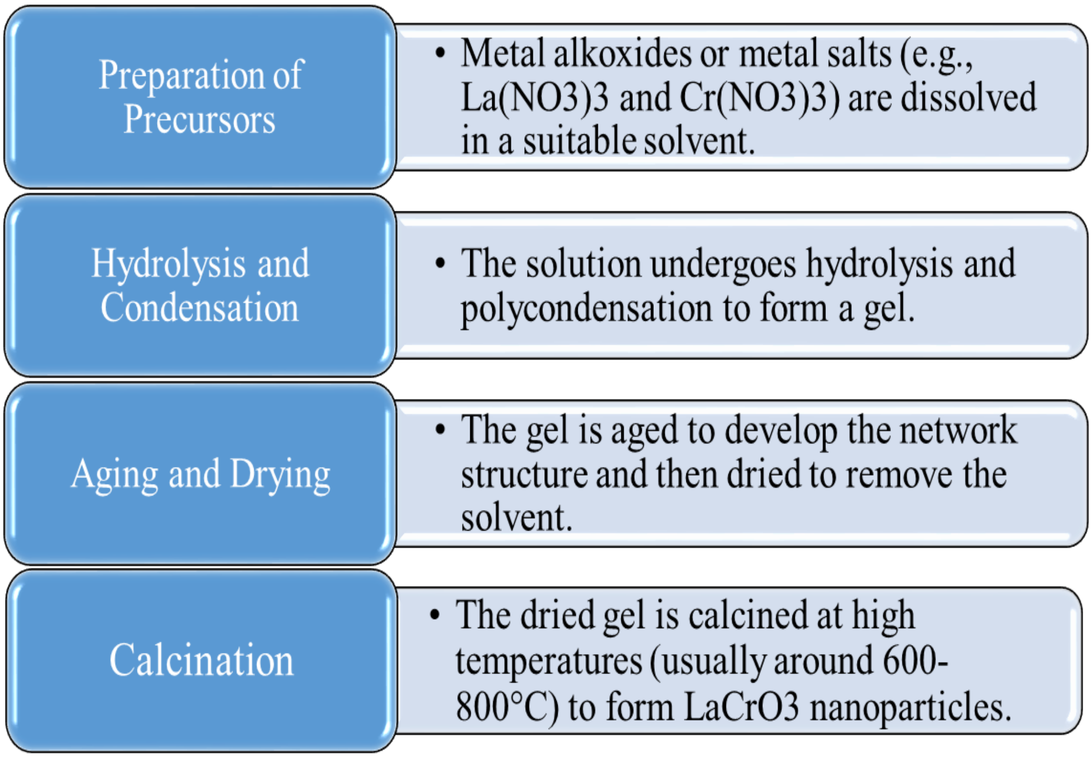

Figure 1: Steps for synthesis of $LaCrO_3$ nanoparticles by sol gel method

2.2 Hydrothermal Synthesis

This method produces well-crystallized nanoparticles with controlled size and morphology. Also lower synthesis temperatures compared to other synthesis method is required. This method produces well-crystallized nanoparticles with controlled size and morphology.

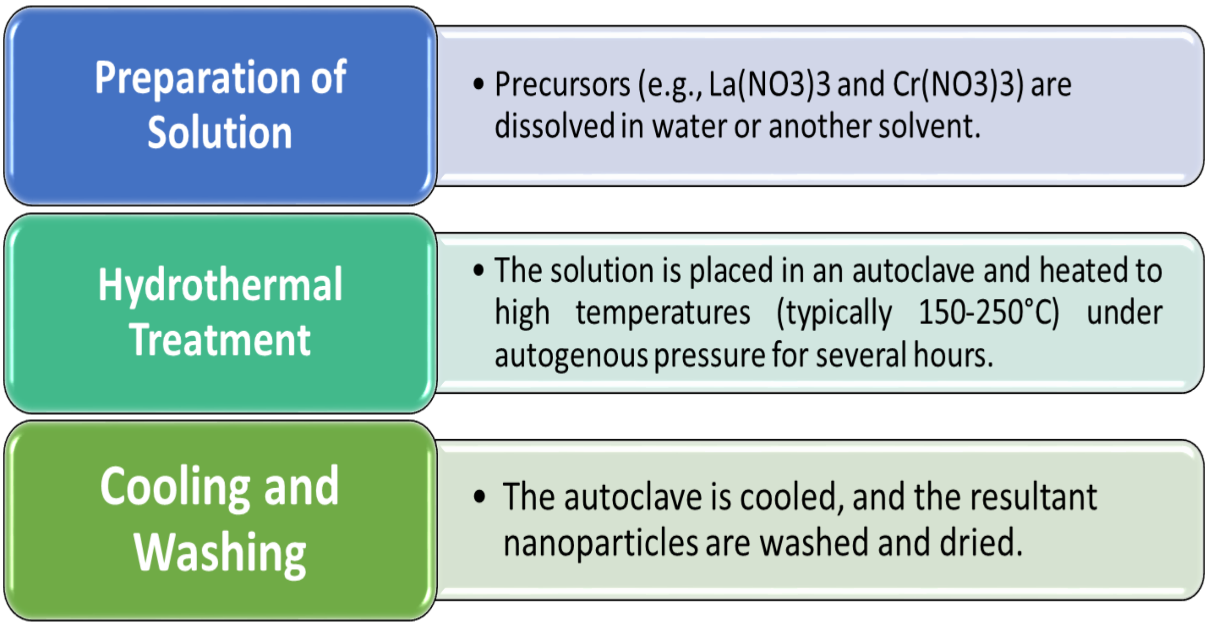

Figure 2: Steps for synthesis of $LaCrO_3$ nanoparticles by hydrothermal method

2.3 Co-Precipitation Method

The Co-Precipitation method is another effective technique for synthesizing LaCrO3 nanoparticles. This method involves the simultaneous precipitation of lanthanum and chromium salts from a solution, followed by drying and calcination to form the desired nanoparticles as shown in Fig.3.The Co-Precipitation method is straightforward and can be easily scaled up for large-scale production.

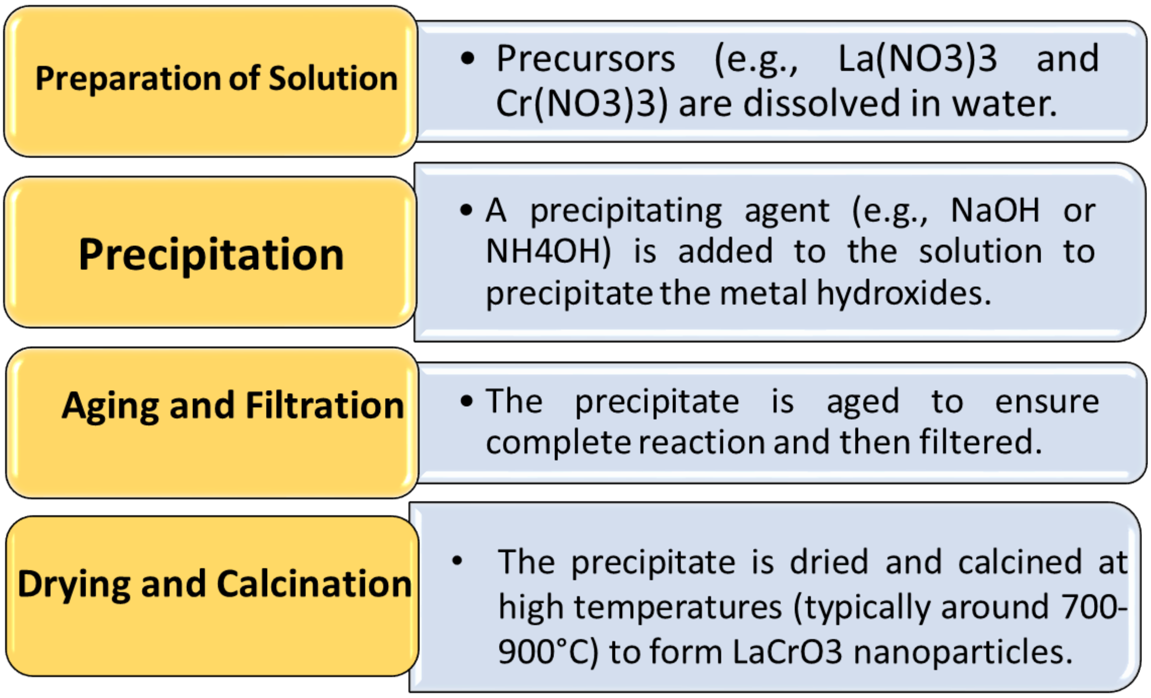

Figure 3: Steps for synthesis of $LaCrO_3$ nanoparticles by Co-Precipitation method

2.4 Combustion method

The Combustion method is a rapid and efficient technique for synthesizing LaCrO3 nanoparticles. This method involves a combustion reaction that generates a significant amount of heat, leading to the formation of nanoparticles. The combustion reaction is very fast, allowing for quick synthesis of nanoparticles. The high temperatures generated during combustion help in forming pure crystalline phases. The exothermic nature of the combustion process reduces the need for external heating.

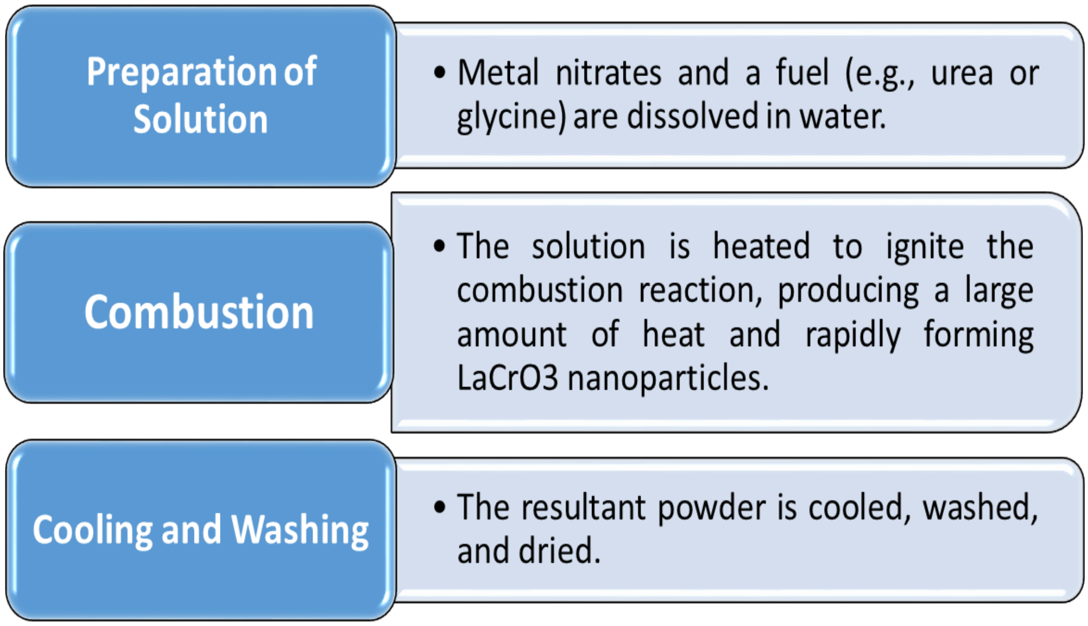

Figure 4: Steps for synthesis of $LaCrO_3$ nanoparticles by combustion method

2.5 Other synthesis methods

The other synthesis methods for $LaCrO_3$ nanoparticles are reveal in Fig. 5.

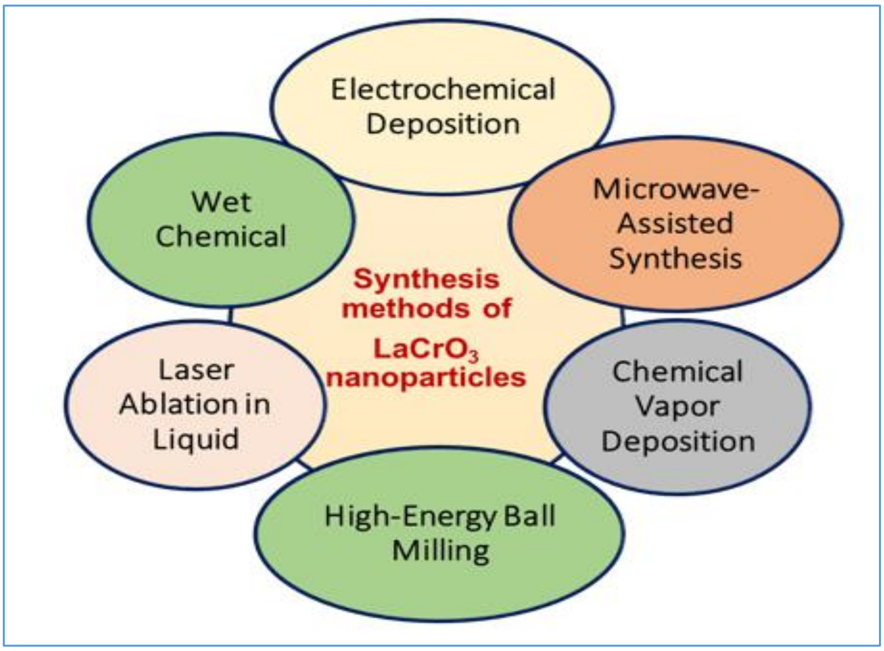

Figure 5: Different synthesis methods for synthesis of $LaCrO_3$ nanoparticles

3. Literature review

Shinde, V. S., et al. [2018]synthesised $LaCrO_3$ nanoparticles by simple sol gel method. The synthesis of $LaCrO_3$ nanoparticles by the sol-gel technique is a simple, cost-effective, and efficient method for producing high-purity materials with controlled morphology. In this process, lanthanum nitrate and chromium nitrate are used as precursors, which are dissolved in a suitable solvent, followed by the addition of a chelating agent such as citric acid or ethylene glycol to form a homogeneous gel. The gel is then dried and calcined at high temperatures to obtain $LaCrO_3$ nanoparticles. The prepared nanoparticles are further processed into thick films using the screen-printing method, where a paste of the material is applied onto a substrate through a mesh stencil and then sintered to form a uniform, durable film.Characterization of the nanoparticles begins with X-ray diffraction (XRD), which confirms the crystalline structure and phase purity. The average crystallite size, calculated using Scherrer's formula, is found to be 13.01 nm, aligning with the JCPDS Card No. 33-0701, indicating that the material is a perovskite-type orthorhombic lanthanum chromite. Scanning electron microscopy (SEM) reveals a greyish-black surface morphology of the $LaCrO_3$ nanoparticles. Energy-dispersive X-ray spectroscopy (EDS) confirms the elemental composition, ensuring the presence of lanthanum, chromium, and oxygen in the expected stoichiometry. Infrared (IR) spectroscopy identifies the characteristic stretching frequencies of La–O and Cr–O bonds at 594.08 cm^{-1} and 420.48 cm^{-1}, respectively, further validating the structural integrity of the material. This comprehensive analysis demonstrates the successful synthesis and structural properties of $LaCrO_3$ nanoparticles [19].

Enhessari, Morteza, et al. [2017] $LaCrO_3$ perovskite nanopowders were successfully synthesized using a sol-gel method, incorporating a stoichiometric proportion of lanthanum and chromium precursors with stearic acid as a complexing agent. Structural analysis through X-ray diffraction (XRD) revealed an octahedral framework characteristic of the perovskite structure, with a crystallite size estimated to be around 28 nm. Morphological studies using scanning electron microscopy (SEM) confirmed the particle sizes and provided insight into the uniformity and surface characteristics of the nanopowders.The optical properties of $LaCrO_3$ demonstrated notable activity in the ultraviolet (UV) and visible light regions, highlighting its potential for optoelectronic and photocatalytic applications. The thermal stability of the material was assessed, with the degradation activation energy determined to be approximately 207.97 kJ•mol^{-1} using the Kissinger equation based on a moderate thermal programming profile. Electrical characterization of the perovskite nanopowders revealed a capacitance of 2.970 nF, impedance of 2.522 MΩ, and AC resistance of

16.19 MΩ, emphasizing the material's suitability for applications in electronic devices, energy storage, and sensing technologies. These findings underscore the versatility and functional capabilities of $LaCrO_3$ perovskite nanopowders [20].

Silva Jr, R. S., et al. [2021]Lanthanum chromite ($LaCrO_3$) powder was successfully synthesized using a plant-extract-assisted sol–gel method, employing milk of Janaguba (*Himatanthusdrasticus (Mart.) Plumel*) as an eco-effective chelating agent. Structural characterization through X-ray diffraction (XRD) and Rietveld refinement confirmed an orthorhombic crystalline structure, with average crystallite and particle sizes of approximately 40 nm and 640 nm, respectively. Fourier-transform infrared spectroscopy (FT-IR) verified the presence of characteristic functional groups, while scanning electron microscopy (SEM) provided detailed insights into the material's surface morphology.The optical properties were investigated using UV–vis absorption spectroscopy, revealing a band with a well-defined maximum between 230–350 nm and an optical band-gap energy of 3.33 eV. The photocatalytic performance of $LaCrO_3$ was assessed for methylene blue (MB) degradation under low light intensity (2.87 Wcm^{-2}), achieving a degradation efficiency of 6.3% after 120 minutes of illumination. These results suggest that $LaCrO_3$ has potential as a photocatalyst for treating industrial textile effluents.This study highlights the benefits of utilizing plant-based, eco-friendly synthesis routes, offering a cost-effective and sustainable alternative for producing $LaCrO_3$ powders with promising photocatalytic applications [21].

Maleki, Mansoureh, et al. [2024] The heterobimetallic complex $La[Cr(C_2O_4)_3]\cdot10H_2O$ was synthesized by reacting equimolar aqueous solutions of $K_3[Cr(C_2O_4)_3]$ and $La(NO_3)_3$. This complex served as a precursor for the preparation of nanoperovskite $LaCrO_3$ through exposure to microwave radiation. The microwave-assisted decomposition process led to structural changes in the precursor and the formation of new mineral phases, as confirmed by X-ray diffraction (XRD) and Fourier-transform infrared (FT-IR) spectroscopy.XRD analysis provided detailed insights into the crystalline phases formed, confirming the successful transformation to the perovskite $LaCrO_3$ structure. FT-IR spectroscopy identified characteristic vibrational modes, indicating the breakdown of oxalate ligands and the formation of La–O and Cr–O bonds. The microstructure and morphology of the resulting product were examined using scanning electron microscopy (SEM), revealing uniform particle distribution and nanoscale features. Energy-dispersive X-ray (EDX) analysis confirmed the chemical composition and high purity of the $LaCrO_3$ product.This study demonstrates the efficacy of using heterobimetallic complexes as precursors and microwave radiation as a rapid, energy-efficient method for synthesizing perovskite nanomaterials with controlled morphology and composition [22].

Aamir, M et al. [2021] in this study, $La_{1-x}Co_xCr_{1-\gamma}Fe_\gamma O_3$ (x, y = 0.0, 0.12, 0.36, 0.60) perovskite materials were synthesized via a simple micro-emulsion route. The structural, morphological, and compositional changes due to Co and Fe doping were thoroughly characterized using X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), and energy-dispersive X-ray (EDX) analysis. The results revealed that doping significantly altered the physical and chemical properties of the $LaCrO_3$ perovskite, allowing tunability of its ferroelectric, dielectric, and magnetic behavior.The photocatalytic activity (PCA) of pristine $LaCrO_3$ and Co- and Fe-doped $La_{0.40}Co_{0.60}Cr_{0.40}Fe_{0.60}O_3$ was evaluated under visible light irradiation for the degradation of crystal violet (CV) dye. $La_{0.40}Co_{0.60}Cr_{0.40}Fe_{0.60}O_3$ demonstrated superior photocatalytic efficiency, achieving 77.21% CV dye degradation with a rate constant of 0.01475 min^{-1}. The addition of isopropyl alcohol (IPA) as a scavenger significantly reduced the PCA to 32.5%, with a rate constant of 0.00491 min^{-1}, indicating that superoxide radicals are the primary active species in the photocatalytic reaction.These findings highlight that Co and Fe doping in $LaCrO_3$ can effectively enhance photocatalytic performance under solar light exposure, making the material a promising candidate for environmental remediation, particularly in the degradation of industrial dye pollutants [23].

Shinde, Vrushali Shyamrao, et al. [2020] synthesized undoped and indium-doped lanthanum chromium oxide materials using a cost-effective sol–gel method. The doped materials were synthesized with varying indium ion concentrations (0.1 M% to 0.7 M%) and utilized to fabricate four gas sensors through the screen-printing technique. The structural and chemical properties of the materials were confirmed by characterization techniques, including X-ray diffraction (XRD), scanning electron microscopy (SEM), energy-dispersive X-ray analysis (EDAX), transmission electron microscopy (TEM), and infrared (IR) spectroscopy.The gas-sensing performance of the prepared sensors, including 0.1 M%, 0.3 M%, 0.5 M%, and 0.7 M% In^{3+}-doped $LaCrO_3$, was evaluated for various gases such as petrol vapors, ethanol, ammonia, NO_2, H_2S, and CO_2. Among these, the 0.3 M% In^{3+}-doped $LaCrO_3$ sensor exhibited exceptional sensitivity and selectivity toward petrol vapors, recording the highest response compared to the other doped materials. Additionally, all indium-doped sensors demonstrated good sensitivity to petrol vapors and moderate responses to the other tested gases.The 0.3 M% In^{3+}-doped $LaCrO_3$ sensor showed rapid response and recovery times, along with excellent reproducibility, making it a standout for petrol vapor detection. Key parameters such as selectivity, response time, recovery time, and sensor stability were thoroughly analyzed, establishing the potential of indium-doped $LaCrO_3$ materials as effective gas sensors, particularly for petrol vapor applications [24].

Koli, Prashant Bhimrao, et al. [2020] thiswork highlights the rapid preparation of $LaFeO_3$ thin films using a sol-gel synthesis followed by a spin-coating method. The structural analysis, conducted via X-ray diffraction (XRD), confirmed the formation of monophasic, orthorhombic perovskite $LaFeO_3$. Morphological characterization using scanning electron microscopy (SEM) revealed crystalline $LaFeO_3$ nanoparticles, while energy-dispersive X-ray spectroscopy (EDS) validated the elemental composition of the thin films. Electrical property measurements confirmed the typical p-type semiconducting behavior of $LaFeO_3$.The gas-sensing capabilities of the prepared thin films were extensively studied. The undoped $LaFeO_3$ sensor exhibited excellent sensitivity to methanol vapors, whereas doped $LaFeO_3$ sensors demonstrated superior sensitivity to petrol vapors. The enhanced sensitivity in the doped $LaFeO_3$ sensors is attributed to the increased surface area due to the introduction of dopants, which improved adsorption and reaction sites for gas molecules. The sensors were evaluated for their response time, recovery time, reusability, and selectivity across various gases, including LPG, petrol vapors, CO_2, methanol, ethanol, and acetone.A comparative study of the doped and undoped sensors revealed that doping significantly influences gas-sensing parameters, enhancing the material's performance for specific gases. The detailed investigation of these parameters establishes the potential of both undoped and doped $LaFeO_3$ thin films as effective and reliable gas sensors for diverse applications [25].

Kang, Minkyung, et al. [2013] this study investigates the effects of various additives and precipitants on the synthesis of doped $LaCrO_3$ (lanthanum chromite) nanopowders through a hydrothermal reaction at temperatures ranging from 100°C to 230°C. Several types of precipitants, including NaOH, KOH, NH_4OH, and NH_2CONH_2, were employed to synthesize the $LaCrO_3$ nanopowders. Additionally, the influence of doping elements such as Sr, Ca, and Co on the lanthanum chromites was explored.Characterization of the synthesized nanopowders was performed using X-ray diffraction (XRD), scanning electron microscopy (SEM), and densitometry. The particle size of undoped $LaCrO_3$ nanopowders was approximately 100 nm when KOH was used as a precipitant. The relative density of $LaCrO_3$ doped with calcium and cobalt exceeded 97%, indicating good material compactness.The electrical conductivity of the doped $LaCrO_3$ was measured at 750°C in air using the DC four-point probe method. The highest electrical conductivity was observed for the $La_{0.62}Ca_{0.38}Co_{0.18}Cr_{0.82}O_3$ composition, which exhibited an impressive conductivity of 32.75 S/cm, approximately 30 times higher than that of undoped $LaCrO_3$. The doping of cobalt and calcium significantly enhanced both the density and electrical conductivity of the $LaCrO_3$ materials, making them promising candidates for high-performance applications, such as in solid oxide fuel cells and catalytic processes [26].

4. Applications of $LaCrO_3$ nanoparticles:

$LaCrO_3$ nanoparticles exhibit a range of properties that make them suitable for various applications across different fields. The unique properties of $LaCrO_3$ nanoparticles, including high thermal stability, electrical conductivity, and catalytic activity, make them suitable for a wide range of applications in energy, environmental monitoring, catalysis, electronics, and biomedicine. Continued research and development in the synthesis and functionalization of $LaCrO_3$ nanoparticles will likely expand their applications and enhance their performance in existing ones [25-30]. Fig. 6 shows the different applications of $LaCrO_3$ nanoparticles.

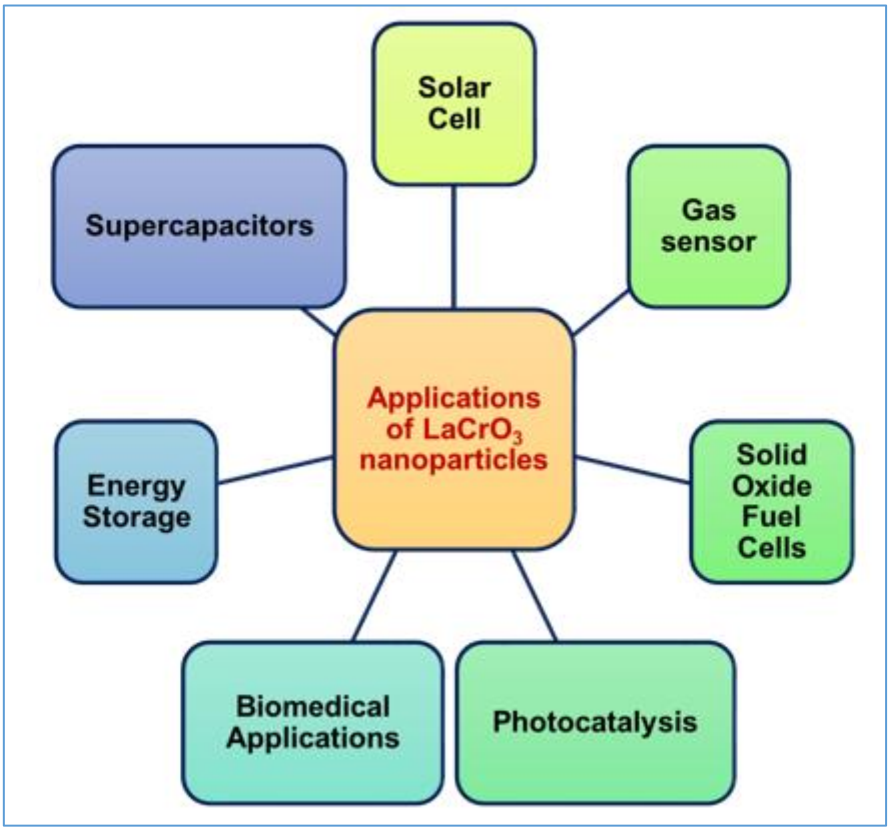

Figure 6: Different applications of $LaCrO_3$ nanoparticles

1. Solid Oxide Fuel Cells (SOFCs)

- **Cathode Material**: $LaCrO_3$ nanoparticles are widely used as cathode materials in SOFCs due to their excellent electrical conductivity, thermal stability, and compatibility with other cell components.
- **Interconnect Material**: They also serve as interconnect materials, which are essential for connecting individual cells in a fuel cell stack while maintaining high electrical conductivity and chemical stability at high temperatures.

2. Catalysis

- **High-Temperature Catalysts**: $LaCrO_3$nanoparticles are used as catalysts in high-temperature reactions due to their stability and resistance to sintering and degradation at elevated temperatures.
- **Environmental Catalysis**: They are employed in catalytic converters for the reduction of harmful emissions from industrial processes and automotive exhausts.

3. Sensors

- **Gas Sensors**: $LaCrO_3$nanoparticles are used in gas sensors due to their high sensitivity and selectivity for detecting gases like CO, NOx, and hydrocarbons. They are particularly useful in environmental monitoring and industrial safety applications.
- **Humidity Sensors**: They can also be used in humidity sensors due to their ability to interact with water molecules, changing their electrical properties.

4. Thermoelectric Materials

- **Thermoelectric Generators**: $LaCrO_3$ nanoparticles are explored for use in thermoelectric materials, which can convert heat into electrical energy. Their high thermal stability and electrical conductivity make them suitable for high-temperature thermoelectric applications.

5. Magnetic Materials

- **Magnetic Storage**: Due to their magnetic properties, $LaCrO_3$ nanoparticles are investigated for use in data storage devices.
- **Magnetic Sensors**: They are also used in the development of magnetic sensors for various applications, including biomedical imaging and environmental monitoring.

6. Electronics

- **Dielectric Materials**: $LaCrO_3$ nanoparticles are used as dielectric materials in electronic components due to their high permittivity and thermal stability.
- **Semiconductors**: They are explored as semiconductor materials in various electronic devices, including transistors and diodes.

7. Photocatalysis

- **Water Splitting**: $LaCrO_3$nanoparticles are investigated for use in photocatalytic water splitting to generate hydrogen, a clean and renewable energy source.
- **Degradation of Pollutants**: They are also used in photocatalysis for the degradation of organic pollutants in wastewater treatment.

8. Biomedical Applications

- **Drug Delivery**: $LaCrO_3$ nanoparticles are explored for targeted drug delivery systems due to their ability to be functionalized with various biomolecules, enhancing the delivery of therapeutic agents to specific sites in the body.
- **Bioimaging**: They are also used in bioimaging applications, where their magnetic and optical properties can enhance the contrast in imaging techniques like MRI and fluorescence imaging.

9. Energy Storage

- **Battery Materials**: $LaCrO_3$ nanoparticles are investigated for use in batteries, particularly in the development of high-capacity, high-stability electrode materials.
- **Supercapacitors**: They are also used in supercapacitors due to their high electrical conductivity and stability, which can enhance energy storage capacity and cycle life.

Conclusion

Lanthanum chromite nanoparticles, a perovskite-structured material, have gained attention due to their unique electrical, magnetic, and catalytic properties. Historically, their synthesis has evolved through various methods to achieve high purity, tailored morphology, and improved functional properties. Early synthesis techniques included solid-state reactions, which required high temperatures and extended durations, often yielding non-uniform particles. To overcome these limitations, wet-chemical methods like sol-gel, hydrothermal, and co-precipitation emerged, offering better control over particle size and distribution. More recently, advanced techniques such as combustion synthesis, microwave-assisted methods, and mechanochemical processes have been employed to enhance efficiency and reduce environmental impact. Applications of $LaCrO_3$ nanoparticles are diverse, spanning from solid oxide fuel cells (SOFCs) as interconnect materials due to their high-temperature stability and ionic conductivity to catalytic processes for pollution control. They are also explored in gas sensing, owing to their sensitivity to reducing and oxidizing gases, and in photocatalysis for environmental remediation. The continuous refinement of synthesis strategies has significantly expanded the scope of $LaCrO_3$ nanoparticles in modern technologies. The future scope lies in the further optimization of synthesis techniques to achieve better control over particle size, morphology, and crystallinity. Green and scalable synthesis methods will be crucial for reducing environmental impact and enabling large-scale production. Additionally, exploring novel doping strategies and composite materials could expand the functional capabilities of $LaCrO_3$ nanoparticles. Advancements in computational modeling and characterization techniques will also play a vital role in understanding and tailoring their properties for next-generation applications in energy storage, biomedicine, and beyond.

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