Synthesis Approaches and Applications of Cobalt Oxide: A Review

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***Abstract*: Now a days, cobalt oxide (Co_3O_4) has gain very much important in the researcher community because of its unique physical, chemical, electrical, magnetic and biomedical properties. Nanomaterials are the materials with at least one dimension measuring less than 100 nm. The nanostructures of Co_3O_4 can be synthesis using various approaches like top down and bottom up approaches. These approaches included chemical, physical and green synthesis techniques. Each synthesis techniques has its own advantageous as well as demerits. The current review paper provide the brief information of these synthesis approaches for Co_3O_4 and applications of Synthesis approaches Co_3O_4 in many areas like as super capacitor, battery, electrodes, optical sensor, energy storage device, solar cell, windows layer and gas sensor, etc. The current review which will help guide future studies on Co_3O_4.**

Keywords: cobalt oxide, synthesis approaches, nanostructures, solar cell, gas sensor.

1. Introduction:

Nature contains a lot of cobalt oxide. Cobalt oxide (Co_3O_4) is the more stable form of cobalt oxide, compared to cobalt (O), cobalt (III), etc. Co_3O_4 is p-type semiconducting and a member of the transition metal oxide group. It exhibits both the antiferromagnetic characteristic and the spinel crystal structure. The optical band gaps range from 1.48 to 2.19 eV. Applications in technology, biomedicine, and the environment can all be found for cobalt oxide (Co_3O_4) nanoparticles [1, 2]. Due to its gas-sensing, catalytic, and electrochemical capabilities, it is one of the most intriguing functional materials. Cobalt nanoparticles can be employed as contrast agents, energy storage, catalysis, pharmaceuticals, electronics, drug delivery methods, and more. The ability of cobalt NPs to be magnetic is a crucial component that creates new opportunities for employing NPs as a delivery system for tailored medication. Cobalt nanoparticles can be employed effectively as sensors to identify a variety of compounds because of their physico-chemical characteristics and small size, it should be mentioned [3, 4].

The Co_3O_4 nanostructures are synthesized using a variety of techniques, such as thermal deposition, hydrothermal, sonochemical method, chemical vapor deposition pyrolysis, chemical vapour deposition, and sol-gel methods. These techniques produce a variety of morphologies, including nanospheres, nanocubes, nanotubes, nanorods, nanoplates, nanofibers, and mesoporous structures [4-8].

2. Synthesis approaches of Co_3O_4 nanoparticles:

The Co_3O_4 nanoparticles are synthesized using top down and bottom up approaches. Top down and bottom up approaches consist three types of synthesis methods such as chemical, physical and biological synthesis methods [7-9]. Figure 1 shows the various synthesis methods implemented for preparation of Co_3O_4 nanoparticles.

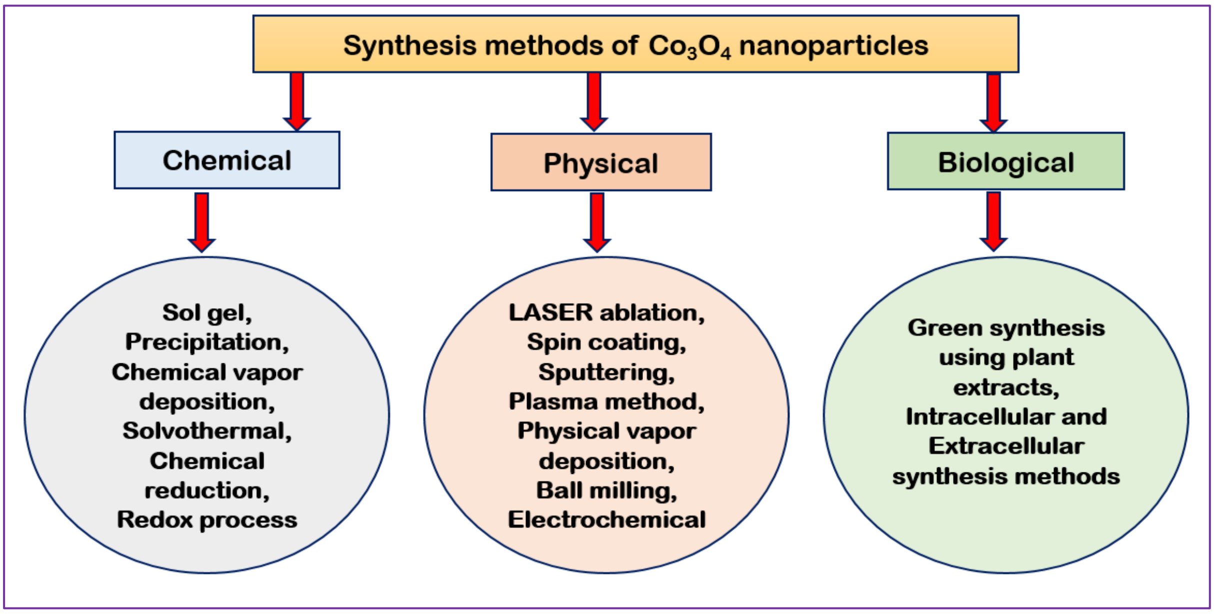

Figure 1: synthesis methods for preparation of Co_3O_4 nanoparticles.

3. Literature survey:

Indira, P. et. al [10] synthesis of Co_3O_4 nanoparticles (NPs) using sol gel method. After successfully synthesis of NPs of cobalt oxide they were used for an electrode material in supercapacitor applications. The formation of Co_3O_4 nanoparticles were analysis by using standard tools like XRD.

Khansari, A. et. al [11] By using thermal treatment process, Co_3O_4 NPs were successfully synthesized. Solid metallorganic molecular precursor was used in the current synthesis method. The as-synthesized products were characterized by powder XRD, FT-IR, TEM and SEM. The maganatic properties of NPs were studied successfully. Authors reported that the hysteresis loops of the obtained samples reveal the ferromagnetic behaviors the enhanced coercivity (Hc) and decreased saturation magnetization (Ms) in contrast to their respective bulk materials.

Yang, Y et. al [12] By using novel technique was used to synthesis of well-separated and spherical tricobalt tetraoxide (Co_3O_4) NPs. In the current work consist three steps: preparation of insoluble carboxyl-containing grafted starch copolymer (ISC), formation of precursor (ISC-Co), decomposition of ISC-Co, and phase transition of Co_3O_4 NPs.

Raman, V. et. al [13] Synthesis of Co_3O_4 NPs with block and sphere morphology, and investigation into the influence of morphology on biological toxicity. Author reported that the morphology of NPs and surface area (Sw) contribute to toxicity, which may have implications for their biological applications.

Dewi N. et. al [14] synthesis of Co_3O_4 NPs using green synthesis approach. In this work, Euphorbia heterophylla L. leaves extract were used for synthesis. Cobalt nitrate hexahydrate, $Co(NO_3)_2.6H_2O$ was used as an source material of cobalt oxide. FT-IR spectrometry showed the presence of Co (II)-O and Co (III)-O bond at the wavenumber of 574 and 699 cm^{-1}, respectively. UV-Vis Spectroscopy indicated the typical peak of Co_3O_4 NPs was found at the maximum wavelength range of 200-350 and 380-600 nm. The particle size distribution of Co_3O_4 NPs was 69.75 nm. Authors reported Co_3O_4 NPs application as photocatalytic activity.

Salavati-Niasari. et. al [15] The heat treatment method has been used to produce Co_3O_4 NPs using the self-prepared [Co(salen)] as the precursor. The suggested processes for producing Co_3O_4 NPs are easy, gentle, and inexpensive, which makes them ideal for scalability. Furthermore, it is reasonable to assume that these methods will be expanded in order to produce a wide variety of significant ultrafine semiconducting metal-oxide powders. The Co_3O_4 NPs optical absorption characteristics were studied by authors. They reported with direct transitions at 1.53 and 2.02 eV, the data show that the nanoparticles are semiconducting. The optical property test reveals a shift in the nanoparticles' absorption peak toward short wavelengths. The quantum effect may also be responsible for the blue shift occurrence.

Liotta L.et. al [16] reported synthesis, structural properties and catalytic applications of Co_3O_4 nanocrystals and Co_3O_4–MO_x binary oxides. Author provided thorough overview on the synthesis, structural characteristics, and catalytic uses of Co_3O_4 nanocrystals and Co_3O_4 -MOx binary oxides in CO, CH_4, and VOC oxidation at low temperatures. It starts off by discussing the main synthetic techniques, fundamental characteristics of Co_3O_4 nanocrystals, and Co_3O_4-MOx binary oxides. It then emphasizes the connection between the unusual structure of Co_3O_4 nanocrystals and their catalytic activity.

Qiu, H.J et al [17] prepared cobalt-oxide-based nanomaterials and study their applications in the field of superior electrochemical energy storage devices. In this review, authors provided overview of recent advances in the rational design and fabrication of different cobalt oxide-based nanomaterials and their performance in lithium storage, including 1D nanowires/belts, 2D nanosheets, 3D hollow/hierarchical structures, hybrid carbon nanostructures (amorphous carbon, carbon nanotubes, and graphene), and mixed metal oxides. Authors reported by rational design, such cobalt-oxide-based nanomaterials are very promising as next generation LIB anodes.

Bibi I. et al [18] synthesized of Co_3O_4 NPs using eco-friendly green synthesis approach. Bibi did characterization of synthesized cobalt-oxide nanoparticle and study their photo-catalytic activity. Using Punica granatum peel extract and cobalt nitrate hexahydrate at low temperatures, Co_3O_4 NPs were prepared. X-ray powder diffraction, scanning electron microscopy, energy-dispersive X-ray, atomic force microscopy, Fourier transform infrared spectroscopy, and UV-visible methods were used to analyze the synthesized Co_3O_4 NPs. The Co_3O_4 NPs had an extremely homogeneous shape and ranged in size from 40 to 80 nm. Remazol Brilliant Orange 3R dye was used to test the photo-catalytic activity of the produced NPs, and a degradation of 78.45% was attained utilizing 0.5 g of cobalt-oxide NPs and a 50-minute irradiation period.

Raman V. et al [19] Synthesized of Co_3O_4 NPs with block and sphere morphology, and investigation into the influence of morphology on biological toxicity. Utilizing different surfactants Co_3O_4 magnetic nanoparticles with block and sphere morphologies were prepared, and the toxic effects of the particles was evaluated by observing zebrafish biomarkers of nanoparticle toxicity.

Pagar T. et al [20] this study has provided an overview of recent research findings in the area of plant parts-based biogenic synthesis of Co_3O_4 NPs. When compared to Co_3O_4 NPs, this literature review showed that the majority of studies on biosynthesis of gold, silver, and zinc oxide NPs. Therefore, the scientific community needs to pay extra close attention to investigating this straightforward, quick, reliable, clean, eco-friendly, and economically feasible way for producing Co_3O_4 NPs using a bottom-to-top green chemistry strategy. The one pot green synthesis still needs a few improvements, which should be further investigated. Even though the green synthesis has many limitations, such as the inability to control the size and shape of the NPs that are produced, this is not a significant problem for other conventional routes of synthesis. Furthermore, in the future, a greater variety of plant species should be investigated in order to facilitate and speed up the biogenic synthesis of metal oxide nanoparticles. Applications need to be improved, plant material needs to be used to synthesize NPs, and the ideal process for creating Co_3O_4 NPs has to be highlighted in future studies.

Jincy C. et al [21] Synthesis of Co_3O_4 NPs using by the hydrothermal method and study their application for sensing toxic gas at room temperature. Co_3O_4 NPs were characterized by XRD, SEM, EDX, FTIR, and UV Visible spectroscopy tools. The Co_3O_4 NPs had a porous shape and were spherical from SEM. These Co_3O_4 NPs compounds should provide a strong and stable response that is dependent on the NH_3 gas concentration at room temperature. The specific surface area and pore size of the sensor material are connected to the response values of NH_3. Co_3O_4 NPs is a material that shows promise for use in gas sensors, particularly for the detection of NH_3 gas.

Hsueh, T. et al [22] the Co_3O_4 NPs were synthesis by using ultrasonic wave grinding technology. According to the experimental outcomes, Co_3O_4 NPs have an average diameter of roughly 6 nm. To create an Au/ Co_3O_4 NPs /MEMS NO_2 gas sensor, Au nanoparticles are adsorbed onto the surface of Co_3O_4 NPs and merged with a MEMS structure. A typical Au nanoparticle has a diameter of 1 nm. When NO2 gas is injected at 10 ppm and at the optimum working temperature of 136 °C, an Au/ Co_3O_4 NPs /MEMS gas sensor has the largest sensor response and has a higher sensitivity to NO_2 than other gases (SO_2, NH_3, CO, and CO_2).

According to literature survey, it has been found that the Co_3O_4 NPs mostly used in diverse applications of in the field of gas sensor the Co_3O_4 NPs rarely used.

4. Applications Co_3O_4 NPs:

Co_3O_4 is a versatile material with a wide range of applications. Figure 2 shows the different applications of Co_3O_4 nanoparticles.

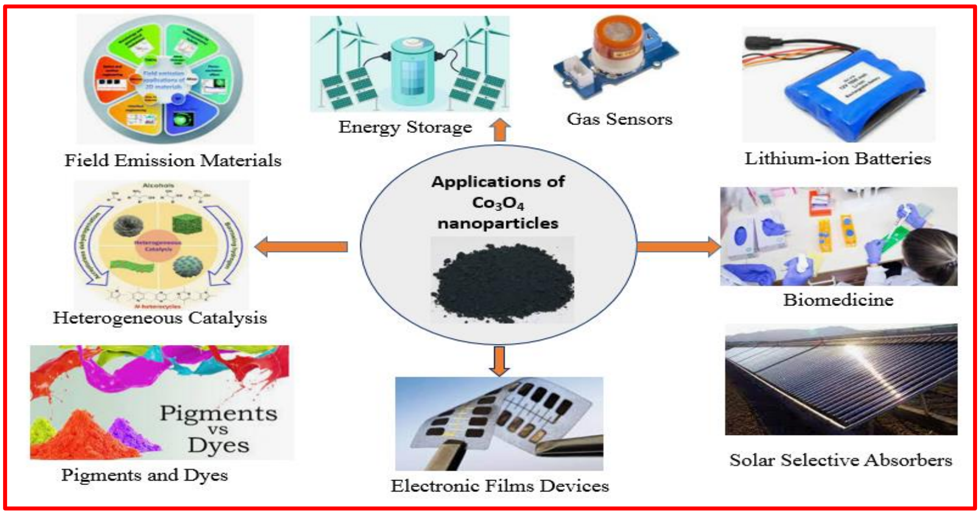

Figure 2: Applications of Co_3O_4 nanoparticles.

The applications of Co_3O_4 nanoparticles including in the area of biomedicine for antibacterial, antiviral, antifungal, therapeutic agents, anticancer, and drug delivery, as well as in gas sensors, solar selective absorbers, anode materials in lithium-ion batteries, energy storage, pigments and dyes, field emission materials, condensers, heterogeneous catalysis, magneto-resistive devices, thin and thick electronic films devices [15-22].

5. Conclusion and Future Scope:

The present short review of current article provided brief information of various synthesis approaches of cobalt oxides as well as different applications of Co_3O_4 nanoparticles. The presented work is definitely helpful those researchers who doing their work on Co_3O_4 nanoparticles.

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