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A Review on Strontium Oxide Nanoparticles

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ABSTRACT

This review article provides a comprehensive overview of the synthesis, characterization, and potential applications of strontium oxide nanoparticles (SrONPs). The focus is on discussing the stability of SrONPs, including their resistance to degradation and corrosion in harsh chemical environments. The review highlights their robust thermal and electrical resistivity, making them suitable for high-temperature applications and maintaining reliable performance in electrical systems. Various characterization techniques, such as UV-Visible spectrometry, FTIR spectroscopy, SEM, XRD, and dynamic light scattering, are utilized to analyze the properties of SrONPs. Additionally, the review explores their potential applications, including their antibacterial properties and suitability for diverse fields such as electronics, energy storage, lighting, and wastewater treatment. This review provides a comprehensive understanding of SrONPs, emphasizing their stability, versatility, and potential for wide-ranging industrial and biomedical applications.

***Keywords*:** Strontium oxide nanoparticles, synthesis, characterization, stability, degradation, corrosion resistance

1. INTRODUCTION

Nanostructure science is a broad and interdisciplinary area of research and developing activity that has been growing explosively worldwide in the past few years. It has the potential for revolutionizing the ways in which materials and products are created and the range and

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nature of functionalities that can be accessed [1]. Different developing applications of nanotechnology utilize the unique properties arising from the nanoscale dimensions of nanomaterials [2].

Research in the area of nanostructured materials has attracted wide attention due to their fascinating optical and electrical properties, which make these materials potentially suitable for applications in electronics, optics, photonics, and sensors [3]. There are various methods to remove the pollutants from the environment like oxidation kinetics [4, 5], biosorption [6, 7], adsorption methods [8-10] of which nanomaterial's are of greater interest due to its high surface active sites. Among metal oxides, nanocrystalline SrO shows excellent thermal stability and good optical properties. Moreover, strontium oxide nanoparticles have made strides in energy storage applications, particularly in lithium-ion batteries. Their exceptional electrochemical performance, high capacity, and stability make them promising candidates for enhancing battery efficiency and capacity, thus addressing the growing demand for energy storage solutions. In the field of biomedicine, strontium oxide nanoparticles have demonstrated potential for improving bone health and tissue engineering. They can stimulate bone regeneration, enhance osteoblast activity, and inhibit osteoclasts, offering promising avenues for orthopedics and dental applications.

Environmental remediation is another area where strontium oxide nanoparticles have shown promise. Their ability to adsorb and immobilize contaminants makes them valuable for removing heavy metals and other pollutants from water and soil, contributing to cleaner and healthier environments.

Additionally, these nanoparticles exhibit photocatalytic activity, enabling them to harness light energy for chemical reactions. Furthermore, the optical and electronic properties of strontium oxide nanoparticles make them attractive for the development of optoelectronic devices. They have been utilized in the fabrication of sensors, LEDs, and FETs, highlighting their potential in the field of photonics. The multifaceted nature of these nanoparticles offers exciting prospects for innovation and progress.

2. SYNTHESIS

Strontium oxide nanoparticles can be synthesized using various methods, each offering distinct advantages and control over particle characteristics (Figure 1). The sol-gel method involves the formation of a colloidal solution that undergoes gelation and subsequent calcination to obtain nanoparticles. Thermal decomposition involves heating strontium-containing compounds in the presence of surfactants or capping agents. Precipitation methods utilize the addition of precipitating agents to strontium salt solutions, followed by further processing and calcination. Hydrothermal/solvothermal synthesis utilizes high-temperature and high-pressure conditions to promote nanoparticle formation. Microwave-assisted synthesis accelerates reactions through localized heating with microwaves. Flame spray pyrolysis atomizes precursor solutions into a high-temperature flame, enabling rapid nanoparticle formation. The choice of synthesis method depends on factors such as desired particle size, morphology, scalability, and application-specific

Requirements [11-14]. Strontium oxide nanoparticles (SrO NPs) hold promise in biomedical fields, such as bone tissue engineering and antibacterial coatings, as well as in optoelectronics, energy storage, environmental remediation, and catalysis.

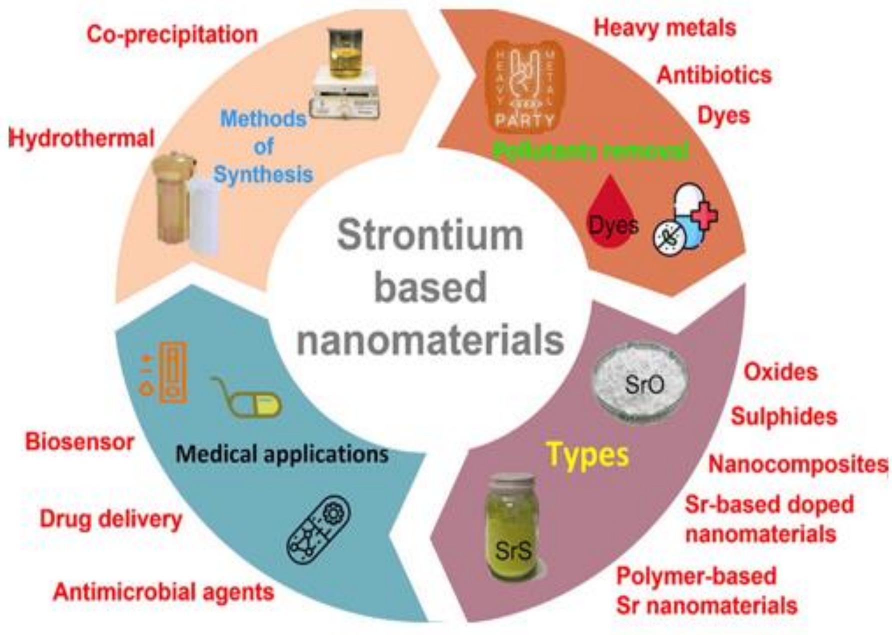

Figure 1. Various methods to synthesis nanoparticles

3. MATERIALS AND METHODS

The stability of strontium-based nanomaterials stems from the inherent properties of strontium, such as its high melting point and robust chemical bonding. This stability allows strontium-based nanomaterials to withstand harsh chemical environments without undergoing significant degradation or corrosion [11]. In addition, the eminent thermal resistivity of strontium-based nanomaterials enables them to withstand high temperatures without losing their structural integrity or properties. This makes them suitable for applications in high-temperature environments, such as aerospace, energy, and industrial processes. Similarly, the excellent electrical resistivity of strontium-based nanomaterials ensures their ability to maintain their electrical properties even in the presence of electrical currents or high-voltage conditions. This makes them valuable for electrical and electronic applications that require stable and reliable performance. The combination of exceptional stability, resistance to chemicals, and notable thermal and electrical resistivity values makes strontium-based nanomaterials highly desirable for various applications. They offer enhanced durability, longevity, and reliability, making them valuable candidates in industries where stability and resistance to corrosion are crucial.

4. MATERIALS AND METHODS A REVIEW

The author of the study focused on the synthesis and characterization of strontium oxide nanoparticles (SrONPs) using a bio-synthesis approach with *Lantana camara* leaf extract. The nanoparticles were characterized using various techniques. To characterize the SrONPs, the authors employed a UV-Visible spectrometer to analyze the absorption properties of the nanoparticles [12]. Fourier Transform Infra-Red (FTIR) spectra were used to examine the functional groups and chemical bonding present in the nanoparticles. Scanning electron microscopy (SEM) was utilized to visualize the morphology and size of the nanoparticles. X-ray diffraction (XRD) was performed to determine the crystal structure of the SrONPs. Additionally, dynamic light scattering was employed to measure the particle size and distribution. The results showed that the biomolecules present in the *Lantana camara* leaf extract acted as both capping and reducing agents during the synthesis process. The XRD analysis indicated that the SrONPs exhibited a cubic crystal structure, as evidenced by the corresponding planes indexed to (101), (112), (202), (213), (310), and (312). This finding provided insights into the crystalline nature of the synthesized nanoparticle [13]. The strontium nanoparticles are unevenly globular in shape, and chaos, and exhibited cluster and partially even surfaces shown from the Scanning Electron Microscope. The antibacterial assay of the synthesized *Lantana camara* strontium oxide nanoparticles was evaluated. The binding effect was more at higher concentrations (100 µl) than the control for the species *E. coli* (21 mm), and *A. niger* (20 mm)

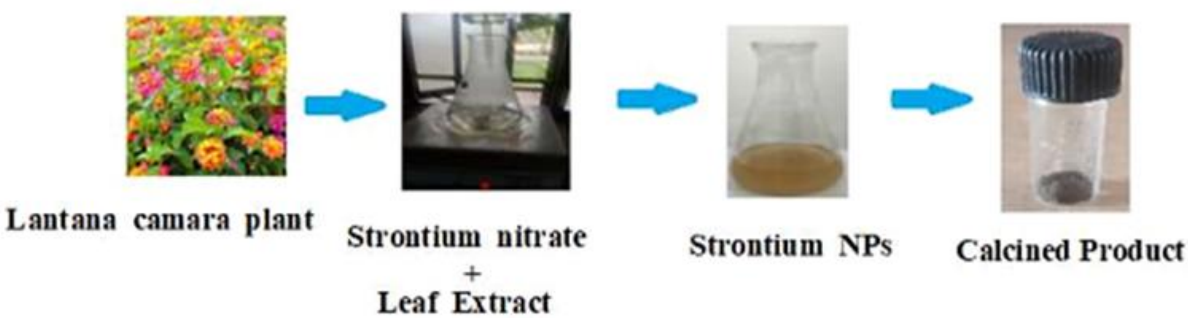

Figure 2. Synthesis of SrONPs from leaf extract of *Lantana camara* plant

The research conducted by P. Anbu, et. al., focuses on the green synthesis of strontium oxide nanoparticles using *Elodea canadensis* extract and evaluates their antibacterial activity [6]. The researchers utilized the extract of *Elodea canadensis*, an aquatic plant, to synthesize strontium oxide nanoparticles in an environmentally friendly manner. The green synthesis approach offers advantages over conventional methods, as it is sustainable and avoids the use of harmful chemicals. The study investigated the antibacterial activity of the synthesized strontium oxide nanoparticles. The nanoparticles were tested against bacterial strains to evaluate their potential as antimicrobial agents. The results of the antibacterial activity study provide insights into the effectiveness of the nanoparticles in inhibiting bacterial growth. The research contributes to the field of nanomaterial synthesis by demonstrating a green and sustainable method for producing strontium oxide nanoparticles. The evaluation of their antibacterial activity adds to the understanding of their potential applications in combating bacterial infections. The findings offer promising prospects for the development of novel antibacterial agents using green synthesis approaches.

The research conducted by K.B. Kusuma et. al., focuses on the synthesis of strontium oxide nanoparticles using the probe sonication method. The researchers employed the probe sonication method to synthesize strontium oxide nanoparticles [14]. The synthesized nanoparticles were further evaluated for their photocatalytic activity and electrochemical sensor applications. The study investigated the photocatalytic activity of the strontium oxide nanoparticles by studying their ability to degrade a specific target substance under light irradiation. The electrochemical sensor studies aimed to explore the nanoparticles' potential for sensing applications, particularly in detecting specific analytes. The findings of the research contribute to understanding the synthesis process of strontium oxide nanoparticles using the probe sonication method. The study also provides insights into the photocatalytic activity and electrochemical sensing capabilities of the synthesized nanoparticles. The results obtained from this research hold potential for various applications in the field of sensors and catalysis.

The crystallite size of the SrO samples is found to be between 41 and 45 nm.

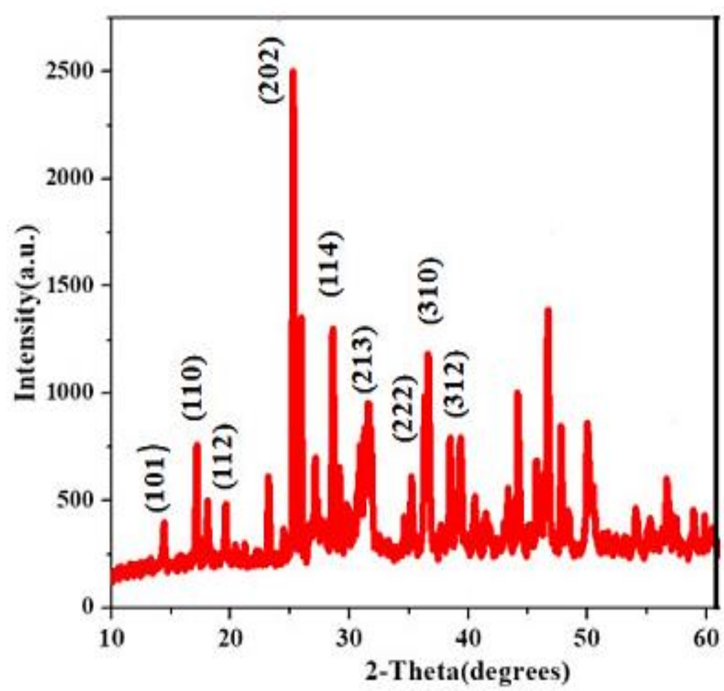

Figure 3. XRD structure of SrONPs [14]

This study aims to synthesize SrO nanoparticles using a new method, as they hold important and specific uses. The researchers utilized the aqueous extract of *Erzincan Cimin* grape (*Vitis vinifera, Cimin*) as a bio-reduction agent to obtain SrO nanoparticles [15].

The synthesis process involved adding a biosynthesis medium containing 0.1 M Sr(NO3)2 to the *Cimin* grape extract. Structural characterization of the synthesized SrO nanoparticles was performed using SEM, EDAX, and FTIR techniques. The mean particle size was calculated to be 28.6 nm based on X-Ray diffraction analysis. SEM analysis revealed the synthesis of porous nanostructured particles ranging in size from 20 to 50 nm. The maximum absorbance of the SrO nanoparticles was observed at 203 nm. Experimental data indicated that the optimum synthesis conditions for SrO nanoparticles were achieved at 90 minutes, 40 °C, and pH 8. The newly synthesized nanomaterial is expected to find applications in various fields due to its favorable physical and chemical properties. The study presents a novel approach for the synthesis of SrO nanoparticles using the *Erzincan Cimin* grape extract. The findings contribute to the understanding of SrO nanoparticle synthesis and their potential applications in different areas.

The study conducted by Rizwan Akram, Ziyad M Almohaimeed, Adeela Bashir, Muhammad Ikram, Karwan Wasman Qadir, and Qayyum Zafar focuses on the synthesis and characterization of pristine and strontium-doped zinc oxide (ZnO) nanoparticles for the application of methyl green photo-degradation [16]. The researchers describe an effective method for degrading methyl green dye using both pristine and strontium-doped ZnO nanoparticles as photocatalysts under visible light illumination. The structural analysis through X-ray diffraction confirms that both photocatalysts exhibit a hexagonal wurtzite structure, with no additional phase formation in the case of Sr-doped ZnO.

The optical properties of the synthesized photocatalysts were investigated using UV-Vis absorption spectroscopy, revealing a slight decrease in band gap energy from 3.3 to 3.2 eV for Sr-doped ZnO. This change was further confirmed by the quenching of the Photoluminescence (PL) emission spectrum, indicating sub-band level formation between the valence and conduction bands due to the incorporation of Sr^{2+} ions into the ZnO host. Morphological analysis using Field Emission Scanning Electron Microscope showed that both photocatalysts had a surface texture based on nanoparticles (NPs). In the photocatalytic activity study, after 30 minutes of visible light irradiation, approximately 65.7% and 84.8% photocatalytic degradation of methyl green dye were achieved using pristine and Sr-doped (2 wt%) ZnO photocatalysts, respectively. The rate of the photocatalytic reaction (K) was observed to be approximately 0.06399 min^{-1} for Sr-doped (2 wt%) ZnO and approximately 0.03403 min^{-1} for pristine ZnO.

The significantly improved photodegradation activity of the Sr-doped ZnO photocatalyst can be attributed to its relatively broader optical absorption capability, surface defects, and enhanced charge separation efficiency.

The study conducted by B. Sumedha, Sandhya Sundar, Rajesh Kumar Shanmugam, Ramya Ramadoss, Suganya Paneerselvem, and Pratibha Ramani focuses on the synthesis and evaluation of strontium nanoparticles using Oolong tea as a reducing agent [17]. Oolong tea contains flavonoids such as catechins and theaflavins, which make it an effective choice for synthesizing metal nanoparticles compared to other methods. The researchers prepared Oolong tea extract and added strontium oxide to synthesize the strontium nanoparticles. The cytotoxicity and embryonic toxicology of the nanoparticles were assessed by studying their effects on the hatching rate and viability rate of zebrafish embryos at different concentrations.

The antimicrobial potential of the nanoparticles was also evaluated by measuring the zone of inhibition against common oral pathogens, including *Staphylococcus aureus*, *Streptococcus mutans*, *Enterococcus faecalis,* and *Candida albicans*. The results showed concentration-dependent alterations in the hatching and viability rates of zebrafish embryos when exposed to the strontium nanoparticles. The antimicrobial assessment revealed significant zone of inhibition values, with mean values of 23 mm against *Enterococcus faecalis*, 33 mm against *Staphylococcus aureus*, 23 mm against *Streptococcus mutans*, and 9 mm against *Candida albicans* by the end of the fourth day. The study concludes that Oolong tea, when combined with strontium nanoparticles, exhibits strong antimicrobial activity. This finding suggests potential applications in preventive dentistry, where the antimicrobial properties of Oolong tea combined with the advantages of strontium nanoparticles can be utilized.

The article authored by Alex Tangy, Indra Neel Pulidindi, Asmita Dutta, and Arie Borenstein discusses the utilization of strontium oxide nanoparticles (SrO NPs) for biodiesel production and highlights recent advancements in this area [18]. Biodiesel is considered a renewable and eco-friendly alternative to conventional fossil fuels, but there are challenges in large-scale production. In the search for an efficient and reusable solid base catalyst for the transesterification reaction involved in biodiesel production, strontium oxide has emerged as a promising choice. SrO exhibits strong basicity, making it highly active and selective in the transesterification process. Compared to other alkaline earth metal oxides, SrO demonstrates the highest activity. The authors review the recent progress made in the development of synthetic methods for SrO nanoparticles, as well as the use of SrO hybrids, which have shown improved performance in biodiesel production. They discuss the advantages of SrO-based nanocomposites in this context. Additionally, the article explores potential support materials that can enhance the catalytic performance of SrO nanoparticles, with a focus on their commercial implications. These advancements in SrO nanoparticle synthesis and utilization offer promising prospects for enhancing the efficiency and scalability of biodiesel production.

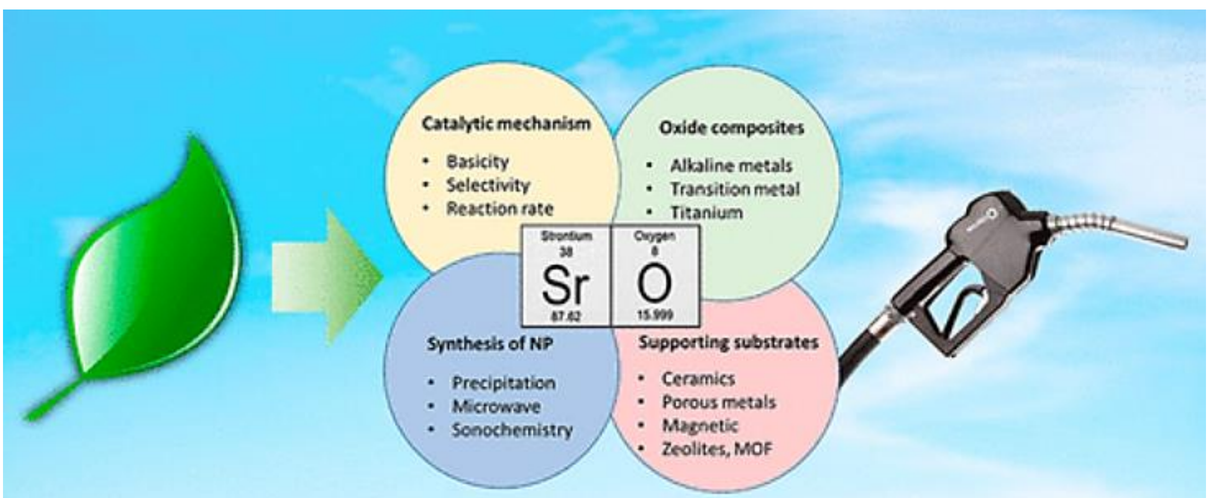

Figure 4. SrO NPs for biodiesel production [11]

The study focused on the synthesis and characterization of strontium oxide nanoparticles using the sol-gel method. Strontium nitrate and sodium hydroxide were used as precursors, and the synthesis was carried out at room temperature, making it a simple and cost-effective method. The characterization of the strontium oxide nanoparticles was conducted using X-Ray diffraction (XRD), scanning electron microscopy (SEM), and Fourier transform infrared (FTIR) spectroscopy [19]. The XRD analysis revealed that the nanoparticles were crystalline in nature. The crystalline size of the nanoparticles was calculated using the Debye-Scherrer formula, and it was found to be approximately 80 nm. SEM was employed to observe and investigate the morphology of the nanoparticles. The results showed that at room temperature, the nanoparticles exhibited a pseudo-spherical shape. Upon calcination at 200 °C, 400 °C, and 600 °C, the nanoparticles transformed into cubic and eventually cylindrical shapes, indicating agglomeration with increasing temperature. The FTIR spectrum of strontium oxide exhibited a peak at 854.64 cm^{-1} , which corresponds to the Sr-O bond, confirming the presence of strontium oxide in the synthesized nanoparticles. Overall, the study successfully synthesized strontium oxide nanoparticles using the sol-gel method and characterized their crystalline nature, size, and morphology. The findings contribute to the understanding of the synthesis process and properties of strontium oxide nanoparticles, paving the way for their potential applications in various fields.

The study focuses on the detection of cervical cancer using nanomaterial-based systems and specifically investigates the use of a strontium oxide-modified interdigitated electrode (IDE). Cervical cancer is a life-threatening condition characterized by the uncontrolled growth of abnormal cells in the cervix [20]. The researchers fabricated the strontium oxide-modified IDE using the sol-gel method and characterized it using scanning electron microscopy and high-power microscopy. The analysis of the bare devices demonstrated reproducibility in the fabrication process, and pH scouting revealed the reliability of the device within a pH range of 3 to 9. The sensing surface of the IDE was tested for the detection of squamous cell carcinoma antigen (SCC-Ag), which is a potential biomarker for cervical cancer. The detection limit was found to be 10 pM, and the sensitivity ranged between 1 and 10 pM, as calculated by 3σ. This demonstrates the high sensitivity of the strontium oxide-modified IDE for detecting SCC-Ag. To assess the specificity of the detection system, major proteins from human serum, such as albumin and globulin, were used in experiments.

In this study, a novel approach to synthesizing strontium oxide (SrO) nanorods integrated with polyaniline (SrO-PANI) is presented using a physical blending method. The synthesized nanocomposites (NCs) are characterized using scanning electron microscopy (SEM) and X-Ray diffraction (XRD) [21]. The electrochemical performance of the NCs is evaluated for energy storage applications, particularly in the context of asymmetric supercapacitors. The results show that SrO-PANI NCs exhibit superior electrochemical performance compared to pure PANI and SrO nanorods. At a current density of 0.8 A g^{-1} in a three-electrode assembly, the NCs achieve a maximum specific capacity (Qs) of 258 C g^{-1} and demonstrate improved electrochemical stability. A supercapattery device is fabricated using the SrO-PANI NCs, which exhibits enhanced energy density of 24 Wh kg^{-1} and a maximum power density of 2240 W kg^{-1}. Furthermore, the device demonstrates excellent cyclic stability, retaining 114% of its capacity after 3000 galvanostatic charge-discharge (GCD) cycles. The study further investigates the capacitive and diffusive contributions to the total capacity of the device using Dunn's model. The cost-effectiveness of the SrO-PANI NCs makes them highly suitable for efficient energy storage devices.

The research conducted focused on improving the properties of medical silicon insoles, particularly for diabetic patients. Although silicon is an excellent material for fabricating insoles due to its hyperelasticity and chemical properties, it has the drawback of causing heavy perspiration during usage, which is undesirable for diabetic patients. To address this issue, the researchers added nano strontium oxide to the silicon material to confer antibacterial properties and enhance humidity absorption [22]. Different percentages of nano strontium oxide (0.03%, 0.05%, and 0.07%) were incorporated into the silicon insoles. Antibacterial tests and humidity measurements were performed to evaluate the effectiveness of the modified insoles. The results showed that the addition of nano strontium oxide significantly improved the humidity absorption of the insoles. The humidity absorption percentages for the different concentrations of nano strontium oxide were reported as 5.45%, 10.36%, and 14.54%, respectively, compared to only 2.3% for pure silicon insoles. This indicates a substantial enhancement in moisture absorption capability.

Furthermore, the antibacterial tests demonstrated that the insoles containing nano strontium oxide showed no presence of microbes. This highlights the antimicrobial properties conferred by the addition of nano strontium oxide, which is crucial for maintaining hygiene and preventing infections in diabetic patients. The research suggests that by incorporating suitable nanomaterials, such as nano strontium oxide, the properties of medical silicon insoles can be improved, providing better humidity absorption and antibacterial functionality. This emphasizes the importance of both the substrate's geometry and material, as well as the incorporation of appropriate nanomaterials, in enhancing the performance and suitability of medical insole applications.

The study conducted by J. B. Reshmi, S. Grace Victoria, and I. Jane Preetha focuses on the synthesis and optical characterization of strontium oxide nanoparticles (SrO NPs). SrO NPs are highly sought after for their applications in various electronic devices and energy storage systems [23]. The researchers employed a sol-gel method to synthesize the SrO nanoparticles. Characterization of the synthesized SrO powder sample was carried out using several techniques. XRD analysis revealed the crystalline nature of the nanoparticles, and the crystallite size was calculated to be approximately 47.06 nm using the Debye-Scherrer formula. SEM and EDAX analyses provided information about the morphology and purity of the sample, confirming the successful synthesis of SrO NPs. FTIR spectrum analysis confirmed the formation of the strontium oxide phase. UV-Vis spectroscopy demonstrated an absorption peak at 280 nm in the UV region, indicating the optical properties of the nanoparticles. The band gap energy of the SrO NPs was calculated to be 2.30 eV, suggesting their potential for light-emitting applications. The photoluminescence study revealed that the prepared SrO nanoparticles exhibited high-efficiency light emitting properties, making them suitable for various lighting applications. The findings of this study provide valuable insights into the synthesis and optical characteristics of SrO nanoparticles, paving the way for their potential use in electronic devices, energy storage systems, and lighting applications.

The authors conducted a study focusing on the photocatalytic degradation of Congo red dye, a common pollutant in textile industry wastewater. They synthesized Activated carbon-supported and unsupported Strontium oxide (SrO) nanoparticles through the wet chemical co-precipitation method [24]. The nanoparticles were characterized using various techniques, including XRD, SEM, EDX, and FT-IR. The results demonstrated that both unsupported SrO and Activated carbon-supported SrO nanoparticles exhibited excellent photocatalytic activity, degrading approximately 93.3% and 97.6% of the dye, respectively, within 100 minutes of UV irradiation. The study optimized the degradation conditions and confirmed the kinetics of the process using pseudo-first-order kinetics. The work suggests the potential of SrO nanoparticles for effective dye degradation in textile industry wastewater and contributes to the development of sustainable and cost-effective photocatalytic wastewater treatment methods.

5. CONCLUSION

The information presented suggests that strontium oxide nanoparticles have potential applications in various fields, including wastewater treatment, electronic devices, energy storage systems, and lighting applications. The addition of nano strontium oxide to materials such as silicon insoles can improve their properties, such as humidity absorption and antibacterial functionality, making them more suitable for specific applications like diabetic foot care. Additionally, the synthesis and optical characterization of strontium oxide nanoparticles demonstrate their crystalline nature, morphology, purity, and optical properties, which make them promising for electronic and lighting applications. Furthermore, the photocatalytic activity of strontium oxide nanoparticles shows promise for efficient dye degradation in wastewater treatment, particularly in the textile industry.

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