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REVIEW ARTICLE: PROGRESS OF SPINEL FERRITE NANOPARTICLES AND THEIR MAJOR APPLICATIONS

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Abstract: In this report, we have aimed to analyze the progress of 'spinel structure' ferrite materials and their associated applications in diverse fields. The lattice constant of the spinel crystal structure can be assumed to be (a) a = b = c. Spinel ferrite nanoparticles stand as a promising material because of their semiconductive properties and different magnetic behavior. The structural and magnetic properties and the major applications of some spinel ferrite discussed by several researchers have been discussed herein. Major applications of spinel ferrite nanoparticles have been discussed.

Keywords: *Spinel; Synthesis methods; Characterization; Applications of ferrites*

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I INTRODUCTION

In the year 1946, J. L. Snoek, Philips research laboratory, in the Netherlands had discovered soft ferrites [1]. The use of spinel ferrite nanoparticles has revealed radically new structural, electrical, dielectric, and magnetic properties with increased interest from the fundamental and practical point of view [2, 3]. Mahnaz Amiri, Masoud, Salavati-Niasari, Ahmad A Akbari in their investigation stated about the magnetic spinel ferrite nanoparticles could be primarily used for potential application in hyperthermia treatments [4, 5]. Also, Ibrahim Sharifi, H.Shokrollahi, S.Amiri have used ferrite-based magnetic nanofluids used in hyperthermia applications [6]. Meanwhile, the continuous advancement in the technological and biomedical applications of spinel ferrite nanoparticles should be studied extensively. According to D. Ortega and Q.A. Pankhurst, magnetic hyperthermia is superior to other techniques of hyperthermia for cancer treatment because of reduced side effects such as damage to healthy tissues [7, 8]. The increase in temperature is caused due to hysteresis loss/ Neel relaxation [9, 10]. E.S. Day, J.G. Morton, J.L. West have reported in their literature about the heat produced in an external magnetic field raises the temperature of the tissue and this causes the rupture of cells [11]. B. G. Manju et. al. has studied $Cu_{1-x}Ni_xFe_2O_4$ (x = 0, 0.5, 1) nanoparticles using lime juice as a reducing agent by sol-gel method, which has shown a very high antibacterial activity against bacteria (E. coli); coupled with the growth inhibitory ability against microbes [12].

Magnetic spinel ferrite nanoparticles are primarily used for potential application in hyperthermia treatments carried out using a high-frequency induction heating system. To study the magnetic, structural, and other properties of spinel ferrite nanoparticles, and propose the possible hypothesis for the possible mechanism of biomedical applications, viz. surgical implants, sterilization techniques, magnetic hyperthermia, targeted drug delivery, biomedical appliances, and biocompatibility analysis techniques. From ancient times ferrites were known to be the stones that could attract and magnetized when placed in an external magnetic field [13]. Ferrite is the mixed metal oxide having iron oxide as its main constituent such as nickel, copper, cobalt, etc. [14].

$$MeFe_2O_4 = Fe_2O_3 + MeO \quad (1)$$

Ferrite possesses both, electrical as well as magnetic properties and behaves like a semiconductor [15]. High electrical resistivity [16, 17], low eddy current losses [18, 19]. And dielectric losses [20], high saturation magnetization [21, 22], high permeability [23, 24], etc. are the remarkable properties of ferrites. While studying this, we have to be known that one of the important ferrites is magnetite, which can be represented as Fe_3O_4;

$$Fe_3O_4 = Fe^{2+}Fe^{3+}O_4 \quad (2)$$

Magnetite is specialized due to its coexistence of ferrous and ferric cations, which makes them very useful in technological applications [25]. Another ferrite that differs by its crystal structure is 'maghemite', which is very useful for the audio recording media;

$$\gamma - Fe_2O_3 \quad (3)$$

In the vital classification of ferrites, based on crystal structure and the lattice arrangement, ferrite materials are categorized into 3 main groups as spinel, garnet, hexagonal and orthorhombic ferrites [26, 27]. Each ferrite class of ferrites has its significance and has potential applications in different fields. The applications of spinel ferrites, garnet, and hexaferrite are different due to their crystal structure:

2.Crystal structure of spinel ferrite:

According to R.N. Bhowmikand N. Naresh, Spinel ferrites are the mixed metallic oxides [28] of a high resistivity that belongs to the semiconductor family with a general chemical composition AB2X4; where A is a divalent ion such as chromium, manganese, copper, magnesium, cobalt, nickel, zinc, etc., B is a trivalent cation like Fe3+ and X is an oxide anion like O, S or Se [29, 30]. According to N.W.Grimes possess a cubic spinel structure with the Fd_3m- O_h^7 space group [31]. Figure 1 depicts the cubic spinel structure of ferrite (a=b=c).

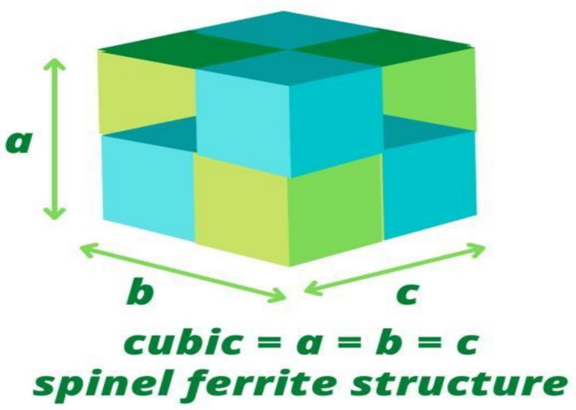

Figure 1. Cubic spinel structure of ferrite.

1 unit cell of the spinel structure ferrite materials there are 8 FCC cells, and 1 FCC cell has a there are 4 lattice points; contributing 32 lattice points for the occupancy of oxide anions [25, 32]. The divalent metal ion in this structure occupies $1/8^{TH}$ of the tetrahedral (A) voids contributing occupancy of 8 lattice points [33]. The trivalent cations occupy 1/2 of the octahedral [B] voids contributing occupancy of 16 lattice points [34, 35]. **Figure 2** depicts the tetrahedral (A)-site and octahedral [B]-site of the cubic spinel structure.

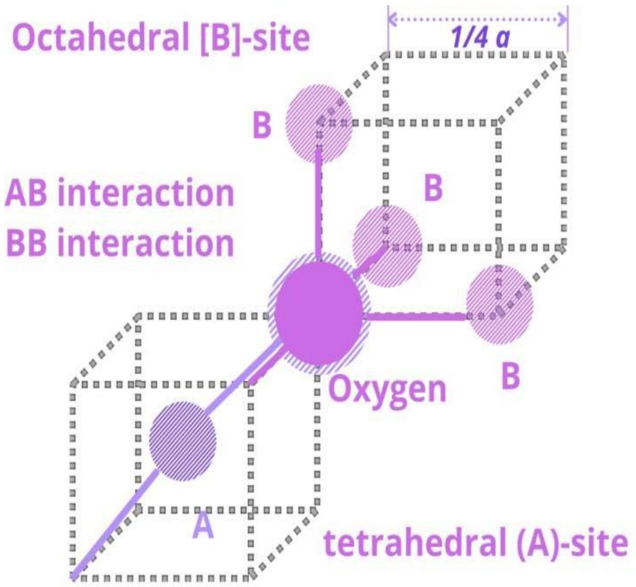

Figure 2 Tetrahedral (A)-site and octahedral [B]-site of the cubic spinel structure.

In Tetiana Tatarchuk Mohamed Bououdina J. Judith Vijay L. John Kennedy has discussed the potential applications of spinel ferrite [36]. S. Manjur Hoque, Md.Amanullah Choudhury, Md. Fakhrul Islam has reported the complex initial permeability saturation magnetization loss factor [37]. Recently, nanoparticles of the spinel-type ferrite have been attracted the extensive interest of scientists, researchers, and technologists due to their excellent physical, chemical, electrical, and magnetic properties targeting specifically various applications [38, 39]. Ferrite nanoparticles are of great interest due to their basic differences in their magnetic as well as other important properties compared to the bulk ferrite [40]. Christine C. Dantas Adriana M. Gama has studied the micromagnetic simulations of spinel ferrite particles [41]. Pressman's, L.; Chapelle, A.; Oudrhiri-Hassani, F.; Barnabé, A.; Tailhades, Ph. has investigated the gas-sensing properties of CuO and spinel ferrite nanocomposite thin films [42]. These structural, electrical, and magnetic properties were found to be significantly influenced by several factors such as the method of preparation, nature, and type of dopant, synthesis parameters, and the synthesis conditions [43]. These physicochemical properties of ferrites are sensitive to the method of preparation, the substitution of cations, microstructure, sintering time, and temperature applied during the synthesis or processing. The distribution, transportation, nature, and the behavior of cations on the tetrahedral (A)-site and octahedral [B]-site in the spinel lattice with the general formula $MeFe_2O_4$ plays a crucial role in deciding these physicochemical properties of spinel ferrites.

3.Applications of spinel ferrite

The magnetic properties of nanoparticles like spinel ferrites found a promising use in various applications like ferrofluids, magnetic information storage media, magnetic refrigeration, magnetic resonance imaging [44], H Mamiya et.al has studied the magneto-caloric effect in spinel ferrite [45]. catalyst [46], antenna rod [3, 47], transformer core [48], memory chip [49], microwave devices [50] sensor: A Chapelle et.al has studied the CO2 sensing properties of spinel ferrite nanocomposite thin film [51, 52], etc.. The remarkable properties such as high saturation magnetization, high coercivity, strong anisotropy along with good mechanical hardness, and chemical stability are not observed in the bulk sample [53, 54]. These properties, along with their excellent physical and chemical stability, make nanoparticles suitable for magnetic recording applications such as audio, videotape and high-density digital recording media, etc. [55-57].

Jonathan R.Scheffe Jianhu Li and Alan W.Weimer have studied the spinel ferrite/hercynite water-splitting redox cycle [58]. A.K. Subramani, K. Kondo, M. Tadac M. Abe, M. Yoshimura, N. Matsushita has reported the high-frequency applications of spinel ferrite in 2010 [59]. Kebede K. Kefeni Bhekie B. Mamba and Titus A.M. Msagati [60] have reported the inevitable application of spinel ferrite in water and wastewater treatment. Henrik Lyder Andersen et.al [61] have prepared magnetic spinel ferrite (MFe_2O_4) via simple, green, and scalable hydrothermal synthesis and studied the crystalline and magnetic structure-property relationship in spinel ferrite nanoparticles. Raghvendra Singh Yadav et.al [62] have studied the impact of sonochemical Synthesis of MnFe2O4 single-phase spinel ferrite structure nanoparticles. Tuyet Nhung Pham, Tran Quang Huy, and Anh-Tuan Le [63] have reported the uses of spinel ferrite-based hybrid architectures for lithium-ion battery, environmental monitoring, and biomedical applications. Mohammad Azam Ansari, Abdülhadi Baykal, Sara Asiri & Suriya Rehman[64] has prepared the chromium-substituted copper ferrite nanoparticles by coprecipitation method and reported the enhances in their antibacterial property. Also, Juan Carlos Aphesteguy, Silvia E. Jacobo, N.N. Schegoleva, G.V.Kurlyandskaya have prepared spinel ferrite by co-precipitation method [65]. It has been proposed for the coating of medical devices to prevent microbial biofilm growth, magnetically drug delivery systems, ointments, cosmetics, creams, and lotions for topical application. Sumithra Y Srinivasan et.al [66] have studied the applications of cobalt ferrite nanoparticles in biomedical nanotechnology, biotechnology, and bioengineering. Meenakshi Dhiman et.al [67] have reported the synthesis of $Mg_{0.9}Mn_{0.1}Sc_xFe_{(2-x)}O_4$ via the sol-gel method and studied the magnetic properties suitable for biomedical applications. As the T.H. Mubarak, O.A Mahmood, and W A Shatti studied the iron-nickel particles used as a contrast medium in an MRI Machine [68]. recording media [69] such as cassettes and CDs, the magnetic stripes in electronic cards, and Rfid magnetic sheet used for digital transactions [70]. The modern applications of ferrites included biomedical drug delivery [71], medical appliances, biological implants in the biological structure, nanorobotic applications, and complex algorithmic technologies in various modern research and development [72]. R.Suresh et.al has studied the wastewater treatment applications of spinel ferrite [73]. Yutao Peng et.al studied the pollution- controlling applications of the ferrite in his literature and exposed future recommendations regarding the water treatments [74].

4.Preparation techniques for spinel ferrite

The dynamic desired product could be continuously designed over the various traditional and new modern synthesis techniques. Among the various methods, some of the good popular synthesis methods are the ceramic method [75], wet-chemical method [76], micro-emulsion method [77], a hydrothermal method [78], auto-clave method [79], spray pyrolysis technique, a salt-melt technique [80], etc. Figure 3 depicts the various preparation techniques adopted by many researchers for the synthesis of ferrite materials all over the world.

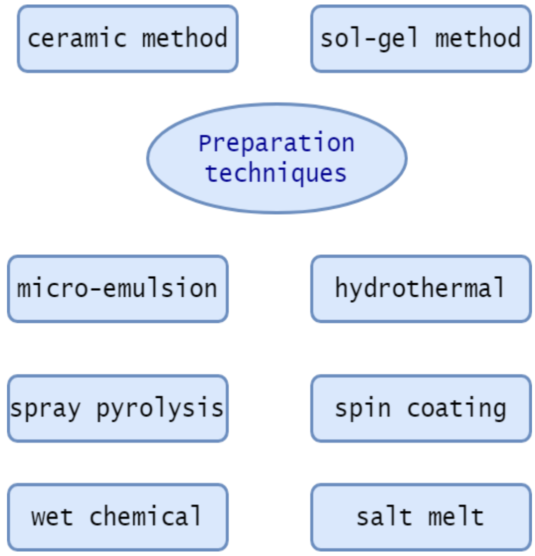

Figure 3: Preparation methods for the preparation of spinel ferrite materials

5. SUMMARY

In this review article, several important aspects of the spinel ferrite nanoparticle dealing with their synthesis, structure, physical properties, and diverse applications are addressed. In the recent literature, it was being noticed about the importance of spinel ferrite nanoparticles viz. biomedical applications, industrial importance, medical diagnosis, photocatalysts, transducers, and so on. Specifically, We have mentioned the antibacterial activity-related study of the spinel ferrite nanoparticles. The future scope and the need for spinel ferrite nanoparticles are kept in front and need to be studied in detail.

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