STM JOURNALS

Research & Reviews: Journal of Physics

ISSN: 2278-2265 (Online)
ISSN: 2347-9973 (Print)
Volume 13, Issue 2, 2024
May–August
DOI (Journal):

https://journals.stmjournals.com/rrjophy/

Review RRJoPHY

A Review Study of Mn-Zn Ferrite with Applications and Synthesis Processes

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Abstract

The distinct magnetic characteristics and adaptability of Mn-Zn ferrites make them broadly applicable in a wide range of industries and applications. Temperature stability, high electricity resistivity, magnetic permeability, permittivity, saturation magnetization, low power losses are among the characteristics of Mn-Zn ferrites. These ferrites particularly in the form of magnetic nanoparticles, have garnered significant interest in cancer research and therapy and biomedical field. Researchers are keenly interested in the synthesis and characterization of Mn-Zn ferrites because of their diverse applications across various fields. Additionally, Mn-Zn ferrites are employed in electronic applications for the production of transformers, transducers, and inductors. Additionally, magnetic fluids, sensors, and biosensors employ these ferrites. Mn-Zn ferrite is an extremely helpful substance for a variety of electronic and electrical uses. Nearly all home appliances, including mobile chargers, LED lights, TVs, refrigerators, juicer mixers, washing machines, irons, and microwaves, require it. In conclusion, Mn-Zn ferrites are an exceptionally versatile and valuable material, with applications ranging from cutting-edge medical research to the essential components found in everyday household appliances. Their distinct properties consistently fuel innovation and progress across various industries, establishing them as a fundamental element of modern technology.

Keywords: Nanoparticles, Ferrimagnetic properties, Synthesis processes, Ferrites, Inductors.

INTRODUCTION

Mostly ferrite refers to a class of ceramic materials composed of iron oxide (Fe_2O_3) combined with one or more additional metallic elements, such as cobalt (Co), nickel (Ni), zinc (Zn), or manganese (Mn) [1-9]. These materials exhibit ferrimagnetic properties, meaning they possess permanent magnetization but are not ferromagnetic. Common ferrite compositions include: Manganese-Zinc (Mn Zn) Ferrites, Nickel-Zinc (Ni Zn) Ferrites, Cobalt Ferrites ($CoFe_2O_4$), Magnesium Ferrites ($MgFe_2O_4$), Barium Ferrites ($BaFe_{12}O_{19}$).

Both the metal and the iron oxide have ferrimagnetic and electrically non-conducting properties. The ferrites have non-collinear arrangement which produce special property, this property provides unequal anti magnetic moments within the material, which permit it to retain spontaneous magnetization even in the absence of an external magnetic field. This unique magnetic arrangement gives rise to several important properties of ferrites, including high magnetic permeability, low eddy current losses, and resistance to demagnetization. These properties make ferrites valuable in a wide range of applications, particularly in electromagnetic devices such as transformers, inductors, and magnetic recording media. Hard ferrites [10-11]. and soft ferrites [12-15]. are the two general categories into which

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Received Date: July 09, 2024
Accepted Date: August 23, 2024
Published Date: August 25,2024

Citation: Pooja Rani, Rohitash Kumar. A Review study of Mn-Zn Ferrite with Applications and Synthesis processes. Research & Reviews: Journal of Physics. 2024; 13(2): 15–

ferrites are divided. Hard ferrites are employed in motors, generators, magnetic separators, magnetic bearings, magnetic couplings, and magnetic lifting devices. They are used in proximity sensors, position sensors, speed sensors, and magnetic reed switches, speakers, headphones, microphones, and other audio devices, electronic devices such as magnetic closures for bags and purses, magnetic door latches, and magnetic toys [16-20].

However, because soft ferrites have little coercivity, it is simple to change their magnetization. The soft is famous for their specific property of high permeability [21-23]. They have low electrical conductivity [24-28], which reduces eddy current losses when they are subjected to alternating magnetic fields. Soft ferrites demonstrate excellent performance at high frequencies, making them valuable in applications such as telecommunications, power electronics, and radio frequency (RF) devices. Soft ferrites can be easily tailored to meet specific requirements by adjusting their composition and processing parameters. This versatility allows for customization based on the needs of different applications. Manganese-zinc (Mn-Zn) ferrites are often preferred over nickel-zinc (Ni-Zn) ferrites for certain applications due to their specific characteristics and performance advantages.

Most prevalent soft ferrites are Mn-Zn ferrites [29-32]. and Ni-Zn ferrites [33-40]. Mn-Zn ferrites tend to be more cost-effective, exhibit higher initial permeability, have lower electrical conductivity, better temperature stability compared to Ni-Zn ferrites. Mn-Zn ferrites are commonly used in applications such as electromagnetic interference (EMI) suppression, transformers, inductors, and various other electronic devices where a combination of high permeability [41]. low losses, and cost-effectiveness is required. MnZn has garnered a lot of interest in academics over the last ten years because of its beneficial properties, which allow MnZn ferrites to be employed in a variety of everyday applications.

Despite the vast scope of the field of magnetic nanostructures and the abundance of well-written reviews on magnetic nanoparticles, MnZn ferrites in particular represent a unique subset of nanoparticles due to the intense interest in soft ferrites among scientists. This review also addresses the selection of synthesis process for the usage of Mn-Zn ferrites in a particular application and critically analyzes methodologies. Sol-gel method [42-45]. co-precipitation method [46-48]. hydrothermal method [49]. citrate precursor method [50]. solid state reaction method [51]. auto-combustion method [52-53]. and microemulsion method [54]. are a few of the methods for the synthesis of MnZn ferrites that are briefly discussed.

Spinel structure is present in Mn-Zn ferrites [55]. The face-centered cubic (FCC) structure of the spinel structure is made up of one primary unit cell and eight sub-unit cells. Each unit cell has two different types of sites: tetrahedral (A) sites and octahedral (B) sites across the whole structure of Mn-Zn ferrite. A total of 64 tetrahedral and 32 octahedral interstitial sites are present. The arrangement of oxygen atoms in the spine is closely packed, with 32 oxygen atoms making up a unit cell. By substituting Fe^{3+} ions, the metal ions may enter the spinel crystal lattice and cause these ions to aggregate on the grain border. These morphological characteristics imply that Mn-Zn ferrite nanoparticle qualities may be adjusted provided the nanoparticle designer chooses the suitable synthesis and characterization methods especially for a certain application. Understanding the various synthesis and characterization methods is necessary to determine the optimal benefits of Mn-Zn ferrites for different applications.

Mn-Zn ferrites typically exhibit higher saturation magnetization [56] compared to other types of ferrites. Mn-Zn ferrites have low magnetic losses [57-58], making them suitable for high-frequency applications such as in power electronics and electromagnetic interference (EMI) suppression. Mn-Zn ferrites have high electrical resistivity, which is advantageous for applications requiring electrical insulation or where eddy current losses need to be minimized, such as in transformers and inductors operating at high frequencies.

Due to their many uses, including those related to hyperthermia [59]. power applications [60-65]. magnetic fluid [66]. high frequency power supply [63]. memory storage devices, TV sets, biomedicines [67]. magnetic resonance, catalysis, etc., MnZn ferrites are of great interest. Through the use of various synthesis techniques, MnZn ferrites' size, shape, morphology, and magnetic characteristics are all continuously being controlled [68].

Synthetic Methods to Prepare Mn-Zn Ferrites

Manganese zinc ferrites, often denoted as Mn-Zn ferrites, are a type of ceramic material widely used in various applications such as inductors, transformers, and magnetic recording media. Here are some common synthesis methods used to prepare Mn-Zn ferrites

1. *Solid state reaction method:* This is one of the most traditional methods for synthesizing ferrite materials. It involves mixing stoichiometric amounts of high-purity metal oxides or carbonates of manganese (Mn), zinc (Zn), and iron (Fe). The mixture is then heated at elevated temperatures (typically above 1000°C) in an oxygen-deficient atmosphere to promote the formation of the ferrite phase. This approach was used by several studies to produce Mn-Zn ferrites [69-70]. The stochiometric amount of $MnCO_3$, ZnO, and Fe_2O_3 in sample form is calcined 1100^0C for 5 hour and cooled with 10^0C/m. PVA was then utilized as a binder, and the powder was pettelized into torroids and tiny disks. After that, sintering was done to obtain the necessary nano ferrites.
2. *Oxidation method:* A chemical technique for creating ferrite nanoparticles is oxidation. The produced ferrite particles are elongated in shape and uneven in shape. This approach has the benefit of producing particles with a homogeneous size distribution and narrow size distribution, but it also forms small-sized ferrite colloids. MnZn ferrite was made by Joseyphus et al [71]. utilizing the oxidation process.
3. *Stearic acid gel method:* Animal and plant fat include stearic acid, also known as octadecanoic acid ($CH_3(CH2)_{16}COOH$), which is a common fatty acid found as a glycerol ester. To create nanoparticles, many researchers are used stearic acid gel. The stearic acid gel technique was employed by Jafarnejad et al. [72] to synthesize $MgCr_2O_4$, and by Enhessari et al. [73]. to synthesize $CoTiO_3$. Through the use of the stearic acid gel technique, Ma et al [74]. produced MnZn ferrite, which has the chemical formula MnxZn1-xFe2O4. Powdered and melted stearic acid was combined with the appropriate concentrations of $MnCO_3$, $Zn(NO_3)_{2.6}H_2O$, and $Fe(NO_3)_{2.9}H_2O$.
4. *Co-precipitation method*: In this method [75]. aqueous solutions containing salts of manganese, zinc, and iron are mixed under controlled pH conditions. By adjusting the pH of the solution, hydroxides of the metal ions are simultaneously precipitated. After precipitation, the resulting gel is washed, dried, and calcined at high temperatures to convert it into the desired MnZn ferrite phase. Thakur et al [76]. synthesized MnZn ferrite using the co-precipitation technique. Using solutions of Mn(NO3)2.4H2O, Zn(NO3)2H2O, and Fe2(NO3)3.9H2O as the starting materials, Anwar et al. [12]. also produced MnZn ferrites using the chemical co-precipitation approach. Using the co-precipitation technique and samarium doping, Yadav et al [77]. investigated the characteristics of ferrite nanoparticles. The Sm-doped ferrites exhibited a single crystalline spinel phase and were very pure. The conduction processes in Mn–Zn nano-ferrites replaced with indium was investigated by Kumar et al. [78]. The oxalate co-precipitation technique was used to synthesis Mn0.4Zn0.6InyFe2-yO4 (y=0.035,0.070, and 0.100), which was then heated in a microwave.
5. *Sol-gel method:* This is very simple and important method to involve the hydrolysis and condensation of metal alkoxides or sols [79-80]. The sol is generalised to a gel. The gel is dried and calcined at elevated temperatures to obtain the desired ferrite phase. When we start to evaporate solvent to sol, then the particles left behind and connect to another regularly. The end product is produced as films or powder that is colloidal in nature. The end product's regulated microstructure makes this process beneficial. Mn-Zn ferrite nanoparticles were produced by

Duan et al [81]. using $Mn(NO_3)_2a$, $Zn(NO_3)_{2.8}H_2O$, and pure $Fe(NO_3)_{3.9}H_2O$ as starting materials. Using a new gelatin technique, Gabal et al. [82] examined Mn–Zn nano-crystalline ferrites generated from spent Zn–C batteries [83]. Although it takes longer to finish the synthesis, this approach has finer control over size and form. The sol-gel technique is inexpensive, requires little processing temperature, and is an easy procedure. The pure cubic spinel structure makes up the prepared ferrite.

6. *Hydrothermal synthesis:* The hydrothermal synthesis method (HSM), an aqueous solution containing metal salts is sealed in a high-pressure vessel and heated at elevated temperatures (usually above 100°C) for a certain period. The high pressure and temperature promote the formation of the ferrite phase. The HSM is used basically create nano particles of controlled size. The magnetic properties for Mn-Zn ferrite studied by Phonget al [84] for Teflon-lined stainless steel.
7. *Microwave hydrothermal synthesis:* The microwave hydrothermal approach is advantageous because it can produce homogenous nanomaterials with tiny particle size distribution due to its extremely quick heating rates. A specific depth can be reached by microwave penetration and sample heating. The microwave hydrothermal approach is advantageous because it can produce homogenous nanomaterials with tiny particle size distribution due to its extremely quick heating rates. As a result, this approach is more cost-effective, quicker, and cleaner than the conventional hydrothermal process [85]. MnZn ferrites were created by Praveena et al. [86] via a microwave hydrothermal method.

Mn-Zn Ferrites: Uses and Applications

Researchers are interested in synthesizing ferrite nanoparticles because of their beneficial magnetic, electrical, and optical properties. These are utilized for different type of applications as medical technology, nano technology, electronics applications, microwave applications etc. [87-96]. The production, characteristics, and uses of ferrites in wastewater treatment [97-100]. biomedicine [101-103]. and catalysis [104-105]. have all been extensively reviewed. Because of its high saturation magnetization [106], high initial permeability [107], and low power loss [108]. Mn-Zn ferrites have a wide range of applications like water purification [109-110]. bio-medical [111]. radar absorption system, magnetic fluid [112]. power applications [113-116]. microwave devices [117]. magnetic fluid [118]. high frequency applications [119-120]. etc. The use of MnZn ferrites in power application has garnered a lot of interest in the scientific community. For use in the production of current convertors [121]. power inductors with magnetic cores [122]. electronic transformer cores [123]. high frequency applications [124]. electronics, and communication [125]. MnZn ferrites have been synthesized for many years.

1. *Microwave apparatuses:* MnZn ferrites are commonly used in microwave apparatuses due to their favorable magnetic properties and low loss characteristics at microwave frequencies. Here's how MnZn ferrites are utilized in microwave applications: MnZn ferrites are employed in the fabrication of microwave absorbers, which are materials designed to absorb electromagnetic radiation at microwave frequencies. The radars system is work of microwave frequencies so these are most useful. Such others are satellite communications, minimize reflection for microwave, and reduced interferences of the signals. Microwave devices can employ ferrite nanoparticles because of their low dielectric losses and poor electrical conductivity [126-128]. Electronic devices made of ferrite nanoparticles can be chemically stable, mechanically robust, and able to function correctly across a large frequency range [129]. The application of MnZn ferrites in microwave devices has several benefits.
2. *Electronic devices: B*ecause Mn-Zn ferrite nanoparticles have improved electrical properties such as high resistivity, low ac conductivity, low power losses, etc. they are employed in the production of several electronic devices. Dobak et al.'s study [130]. focused on component miniaturization brought about by low loss Mn-Zn ferrites. The sun et al [131]. investigated that ZrO_2 effect MnZn ferrite in power supply materials and applications.

3. *Radar absorbing devices:* Environmental contamination from electromagnetic radiation rises as a result of the radiations that radar emits. These radiations shorten the lifespan and safety of electronic gadgets by lowering their performance and efficiency. MnZn ferrite is employed in many electronic applications because it is a member of the soft ferrit class and has high permeability, low power losses, high saturation magnetization, and good electrochemical stability [132-133]. The high Curie temperature and thermal stability of ferrite nanoparticles make them suitable for application in radar absorption devices [134-135].

RESULTS AND VALUABLE DISCUSSION

The material synthesis methods are affect all the properties of ferrites. For instance, sol-gel and hydrothermal methods typically produce smaller, more uniform particles with superior magnetic properties compared to the solid-state reaction method. Future research should focus on optimizing synthesis methods to enhance the magnetic properties of Mn-Zn ferrites while reducing production costs. Additionally, exploring doped Mn-Zn ferrites or composite materials could open new avenues for improving performance in specific applications. In terms of applications, the demand for Mn-Zn ferrites is expected to grow with the advancement of technology in electronics, communication, and healthcare sectors. The development of nano-sized ferrites presents exciting possibilities for biomedical applications, while improvements in synthesis techniques could lead to more efficient and compact electronic devices.

CONCLUSION

The electromagnetic components of Mn-Zn ferrites like transformers and inductors to high-frequency applications in RF circuits and microwave devices are play a critical role in enabling efficient energy transfer, signal processing, and electromagnetic interference suppression. They are also essential in magnetic recording media, medical devics, and power electronics, showcasing their versatility and adaptability to diverse technological needs. Furthermore, Mn-Zn ferrites contribute to advancements in fields such as telecommunications, automotive systems, industrial automation, and healthcare, enhancing the performance, reliability, and functionality of a wide range of devices and systems. With ongoing research and development efforts aimed at optimizing their properties and exploring new applications, Mn-Zn ferrites continue to be at the forefront of innovation, driving progress across various industries and shaping the future of technology.

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