Through the Review of Nanomaterials: Characteristics, Categorization, and uses with an Emphasis on Ferrite Nanoparticles and their Prospects for the Future

Neelapu Sudhakara Rao[1], Mahesh Peyyala[2],
Mavuru Girija Sankar rao[3], Prof. K. Samatha[4]
[1,2,4]Dept. of Physics, Andhra University, Visakhapatnam-530003, India.
[3]Dept. of Physics, TPMH School, Srikakulam-532001, India.
[1]neelapusudhakararao456@gmail.com, Ph:9550720155
[2]maheshpeyyala18@gmail.com, Ph:9963603622.
[3]samatha_k2002@yahoo.co.in, Ph:9441044529.
[4]sankar.mavuru@gmail.com, Ph:9440061894.

Abstract

With their distinct characteristics and wide range of uses in numerous industries, nanomaterials have become a cutting-edge class of materials. This review article offers a thorough introduction to nanomaterials, including information on their fundamental characteristics, classification, and wide range of uses. Ferrite nanoparticles are given particular attention, with an emphasis on their various forms and extensive uses in industries like electronics, energy, environmental remediation, and medicine. The paper also explores the prospective applications and developments of ferrite nanoparticles in the future. This review tries to clarify the relevance of nanomaterials, especially ferrite nanoparticles, and their promising role in influencing future scientific and industrial landscapes by looking at the state of research and technical advancements.

Keywords: Ferrite nanoparticles; Nanomaterials; metal doping; composite; industrial, biomedical applications.

1. INTRODUCTION

Nanoscale materials are defined as a set of substances where at least one dimension is less than approximately 100 nanometers. A nanometer is one millionth of a millimeter-approximately 100,000 times smaller than the diameter of a human hair in fig .1. On the other hand, new studies on hair samples from Egyptian tombs have revealed that hair was colored using a paste made of lime, lead oxide, and water(4). Galenite, or lead sulfide, PbS, nanoparticles, are created during this dyeing procedure. The dyeing paste was able to react with sulfur, a component of hair keratin, and the ancient Egyptians were able to create tiny PbS nanoparticles that allowed for even and consistent coloring.

Nowadays, a variety of fields, including catalysis, water treatment, energy storage, medicine, agriculture, and more, use nanomaterials because of their special qualities. Surface effects and quantum effects are the two fundamental causes of nanomaterials' noticeably altered behavior at bigger dimensions. Because of these elements, nanomaterials have improved or unique optical, mechanical, thermal, magnetic, electrical, and catalytic properties.

Fig. 1 : Shows the different materials in nanometers(4)

Particular size-dependent characteristics of nanomaterials are observed in the 1–100 nm region where quantum phenomena are present. Quantum confinement becomes evident when the material radius approaches the asymptotic exciton Bohr radius, which is the distance between the electron and hole. Put another way, when a material gets smaller, quantum effects become more noticeable and nanomaterials become quantal. All of the charge carriers, which are electrons and holes, are contained inside the physical dimensions of those quantum structures (7). Certain non-magnetic bulk materials, like palladium, platinum, and gold, become magnetic at the nanoscale due to quantum confinement processes, for example significant alterations in electron affinity or the material's capacity to receive or give electrical charges can also be brought about by quantum confinement, and these effects will have an immediate impact on the material's catalytic qualities.The scientific domains of nanoscience and nanotechnology are by their very nature transdisciplinary. Biologists must comprehend not only the fundamentals of nanoscience but also the tools and techniques used in the past to characterize nanomaterials in order to effectively use new bio-based approaches. By assisting biologists in identifying the most effective technologies and collaborators—to characterize their nanomaterials, we anticipate that this study will serve as a catalyst for new partnerships and collaborations among other scientific fields(10). However, we advise carefully considering any potential biological risks associated with these novel materials even in the design stages of such investigations.

1.1. Classification of Nanomaterials

Nanomaterials are incredibly small, with a minimum of one dimension of 100 nm or less. One dimension (such as surface coatings), two dimensions (such as strands or fibers), or three dimensions (such as particles) can all be considered nanoscale for nanomaterials (13) as shown in the fig. 2.

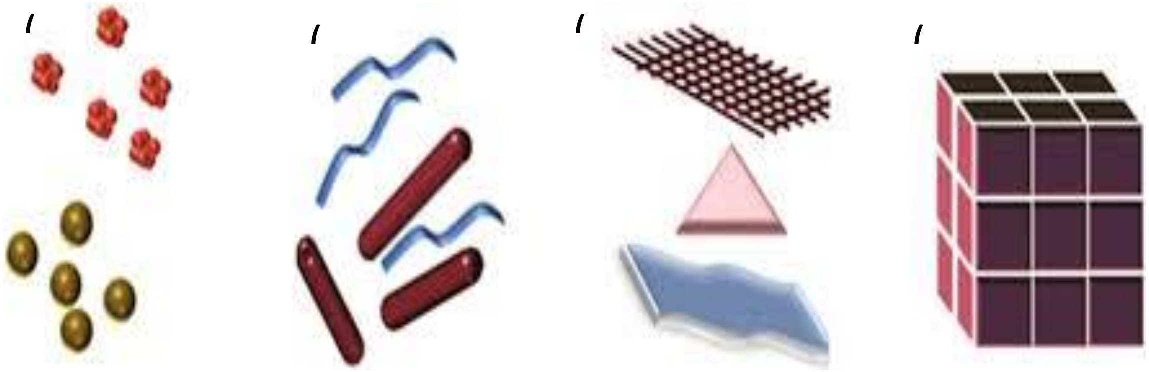

Fig 2 : Classification of Nanomaterials (a) 0D spheres and clusters; (b) 1D nanofibers, nanowires, and nanorods; (c) 2D Nanofilms, nanoplates, and networks; (d) 3D nanomaterials

In the above image, nanomaterials are categorized into four groups according to their dimensionalities.
(a) Zero-dimensional nanomaterials (0-D): All three of the dimensions of these nanomaterials are contained inside the nanoscale range. Ex : Nanoparticles, fullerenes, and quantum dots are a few examples.

(b) One-dimensional nanomaterials (1-D) materials possess a single dimension that extends beyond the nanoscale. Ex : Nanotubes, nanofibers, nanorods, nanowires, and nanohorns are a few examples.

(c) Two-dimensional nanomaterials (2-D): This class of nanomaterials includes two dimensions that are not part of the nanoscale. Ex : Nanofilms, nanosheets, and nanolayers are a few examples.

(d) Three-dimensional (3-D) or bulk nanomaterials: materials in this class are not restricted to any dimension of the nanoscale. Ex : Bulk powders, nanoparticle dispersions, arrays of nanowires and nanotubes, etc. are all included in this class.

1.2. Classifications of Nanoparticles

Organic NPs , Carbon NPs , Inorganic NPs

1.2.1. Organic NPs

NPs composed of proteins, carbohydrates, lipids, polymers, or any other organic component fall under this class.

- ✓ Utilized in the biomedical industry for cancer treatment and targeted medication(Drug) administration

1.2.2. Carbon NPs

NPs that are composed entirely of carbon atoms fall under this class.

- ✓ Utilized in tissue engineering and medication(Drug) delivery applications

1.2.3. Inorganic NPs

NPs that are not composed of carbon or organic elements fall under this class. This class often includes semiconductor, ceramic, and metal nanoparticles. Metal NPs can be monometallic, bimetallic, or polymetallic and they are entirely composed of metal precursors(17). Bimetallic nanoparticles (NPs) can be generated in distinct layers (core–shell) or from alloys.

- Utilized in additional applications, including photonics, optoelectronics, degradation of dyes, and catalysis

2. Properties of Nanomaterials

Nanomaterials are of interest because at this scale unique

- Optical, Magnetic, Electrical, Mechanical and Chemical properties emerge. These emergent properties have the potential for great impacts in electronics, medicine, and other fields

2.1. Common features of Nanomaterials

- Size 1 – 100nm
- Chemically active
- Show different color upon their size
- Strong , hard and ductile, Phase identity, Solubility

3. Synthesis methods of nanomaterials

3.1. Bottom up method (Atoms Clusters Nanoparticles)

Bottom-up methods involve building nanostructures from atomic or molecular components, allowing precise control over composition and structure.

3.2. Top bottom method (Bulk Powders Nanoparticles)

Top-down techniques start with larger materials and carve them down to the desired size, often limiting control over atomic arrangements.

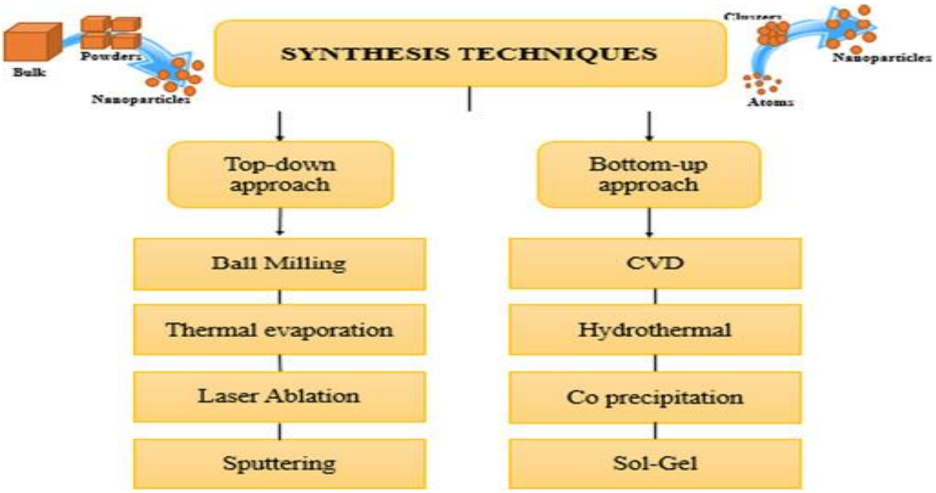

Fig. 3 : Shows the synthesis methods of Nanomaterials(11)

4. Applications of Nanomaterials

Fig. 4 : Shows the applications of NPs and Nanomaterials(16)

Fig. 5 : Shows the applications of bi-Metal doped NPs(19)

5. Aim and Future scope of Nanotechnology

The development of the ‘safe-by-design’ concept for nanomaterials is currently under investigation by scientists. As a young field of study, nanotechnology is predicted to grow significantly in the next years.Scientists estimate that there will be four separate generations of advancements in nanotechnology (28).

- ✓ First—or possibly , passive nanostructures. Ex: carbon nanotubes to strengthen plastics
- ✓ Second— active nanostructures. Ex: Bioactive to provide a drug at a specific target cell or organ
- ✓ Third —advance Nano systems. Ex: Nano robotics
- ✓ Fourth — molecular Nano systems. Ex: control growth of artificial organs.

7. INTRODUCTION TO FERRITES

7.1. Ferrite’s History, Present, and Future

Modern technology has been greatly aided by the invention of magnetic materials. For almost fifty years, ferrites, which are ceramic ferromagnetic materials, have been regarded as extremely significant electronic materials."Ferrites" refers to the majority constituents of magneto ceramics, ferric oxide (oc-Fe203) and some divalent metal oxides.

Fe304 was first prepared by Hilpert1. A true ferrite, magnetite (Fe304) is a naturally occurring mineral that is thought to have been utilized as a mariner's compass in China over 2,000 years ago due to its magnetic properties. However, it wasn't until the turn of the century that ferrites were prepared in any way.

About 60 years ago, ferrites were first put on the market. Nonetheless, due to their significantly worse magnetic characteristics than ferromagnetic alloys, commercial ferrites received little attention. Around the same time, the unique magnetism and increased high frequency applications offered by semiconductors piqued the curiosity of physicists and electronics engineers worldwide (36).Lately, metallurgy, ceramics, and chemistry experts have been working to improve ferrite manufacturing techniques, produce new ferrites, and enhance already-existing ferrite features. The manufacturing of ferrite has skyrocketed in the last few years. The solid solutions of magnetite and cobalt ferrite were found to be strongly magnetic at 300 cC in 1932 by Japanese scientists Kato and Takei8. These solid solutions were also shown to have practical uses. Most of the early ferrites' accomplishments occurred between 1935 and 1970.

8. THE SPINEL FERRITES STRUCTURE

Bragg and Nishikawa determined the structure of spinel ferrite. The general formula compounds AB_20_4 crystallize with a structure similar to that of the mineral spinel ($MgAl_20_4$) (Fig. a). The oxygen parameter u, the cation inversion parameter 'i', and the lattice parameter 'a' are the three crucial parameters related to the atomic organization of the spine(39). To investigate the link between these parameters, oxide spinels are utilized as examples.

$M\ Fe_2\ O_4'$ is the typical chemical formula for spinel ferrite, where M and Fe are the divalent and trivalent (ferric) iron ions, respectively. A and B stand for the tetrahedral and octahedral cation sites, respectively, in the formula AB_20_4. The oxygen anions are grouped in a cubic lattice with the face at the middle. Eight formula units make up each unit cell, with Fe^{3+} and M^{2+} cations occupying the 16(d) and 8(a) sites and O2' anions in the 32(b) sites. Ferrites have a space group of Fd3m O_h with lattice parameters that are typically in the range of 8.3 A^0.Strong super exchange depends on the relative locations of the A and B cations with regard to nearby oxygen anions. This is influenced by the inter atomic distance between the cations and anions as well as the cation-anion-cation bond angle.

The interstitial sites of four fold (a) and six fold (d) oxygen coordination are occupied by the metal ions. In one (Fig. b), the magnetic ion is designated the tetrahedral or A site because four oxygen ions surround it at the vertices of the tetrahedron; in the other, the magnetic ion is surrounded by six oxygen ions at the vertices of the octahedron and is named the octahedral site or B site (Fig. c).

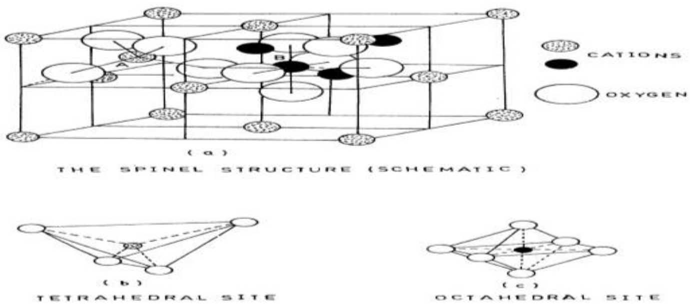

Fig.6: a) Spinel structure b) Tetrahedral sites c) Octahedral sites(40)

8.1 Classifications of ferrites

It is based on the magnetic materials and structure

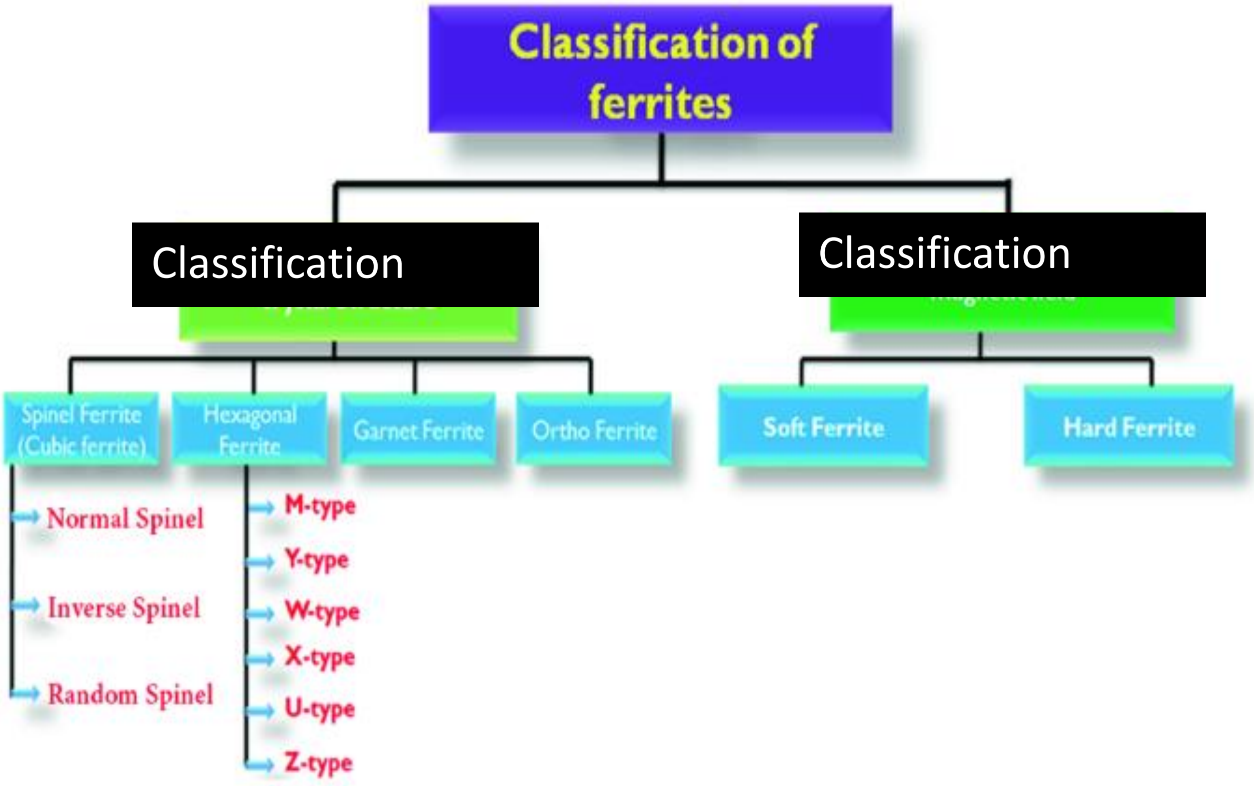

Fig.7: Classification of ferrites (43)

8.2 From magnetic materials

- **Soft Ferrite's(M O.Fe_2O_3)**

  Due to their low coercivity, "soft" ferrites are easily magnetized and demagnetized can conduct magnetic fields its also ferromagnetic material with cubic crystal structure. They are utilized in the electronics sector to create ferrite cores, which are effective magnetic cores employed in high-frequency inductors, transformers, and antennas as well as in different microwave components.Ex: NiZn

- **Hard Ferrite's**

  Since "hard" ferrites have a high coercivity, demagnetization is challenging. Permanent magnets are made with them for use in loudspeakers, refrigerator magnets, and tiny electric motors, among other things. It's also composed of iron and barium oxides .Ex: Barium ferrite($BaFe_{12}O_{19}$)

Table .1 : Comparative properties of soft and hard magnetic materials.

Soft ferrite	Hard ferrite
High saturation magnetization (1e2T)	High saturation magnetization (0.3e6T)
Low coercivity (Hc)	High coercivity
High permeability	Not important, but low

Low anisotropy	High anisotropy
Low magnetostriction	Not important
High curie temperature	High curie temperature
Low losses	High-energy product
High electrical	resistivity Not important

8.3 From structures

1. Spinel ferrites 2. Garnet ferrites 3. Ortho ferrites 4. Hexagonal ferrites

1. Spinel ferrites($M^2Fe^{3+}_2O_4$)

- General formula spinel ferrites Due to their unique composition and structure, mixed metal oxides $(M)^A(Fe_2)^BO_4$ have inherent magnetic, electrical, optical, adsorption, and catalytic characteristics.
- Inverse spinel ferrite formula $[(Fe)^A(M\ Fe)^B{}_2O_4]$
- Mixed spinel ferrite $(M_{1-x}\ Fe)[Fe_{2-x}\ M_x]O_4$
-

Fig.8: Spinel ferrites(51)

2. Garnet ferrites ($M_3(Fe_5O_{12})$)

Garnet ferrites have the chemical formula $M_3(Fe_5O_{12})$, where M is yttrium, or a rare-earth ion, and the structure of the silicate stone garnet. Garnets have dodecahedral (12-coordinated) sites in addition to tetrahedral and octahedral ones, like those found in spinels.

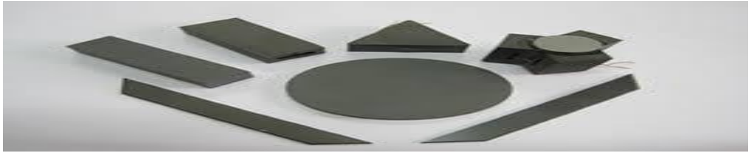

Fig.9: Garnet ferrites(53)

3. Ortho ferrites($MeFeO_3$)

The typical formula for ortho ferrites is $MeFeO_3$, where Me is a massive trivalent metal ion, like Y or a rare-earth ion. With an orthorhombic unit cell, they crystallize in a deformed pervoskite structure.

Fig.10: Ortho ferrites(59)

4. Hexagonal ferrites($BaFe_{12}O_{19}$)

A family of ferrites with a hexagonal crystal structure is known as hexagonal ferrites or hexaferrites. $BaFe_{12}O_{19}$, sometimes known as barium ferrite, BaM, etc., is the most prevalent component. With substantial anisotropy along the c axis, BaM is a ferrimagnetic material that is strong at room temperature. A few building components are stacked in a specific arrangement to create each hexaferrite member.

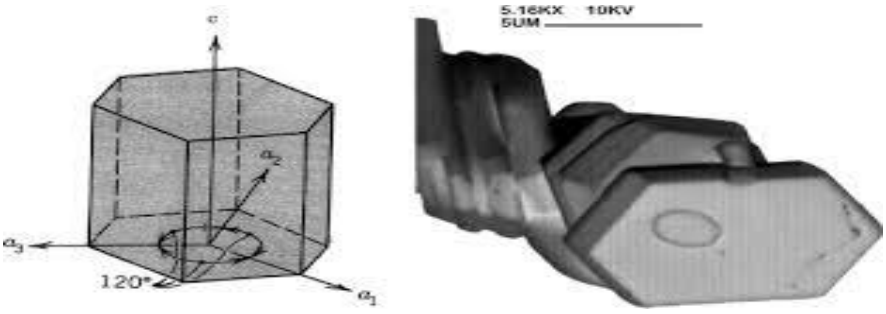

Fig.11: Hexa ferrites(61)

9. Properties of ferrites

- ✓ High electrical resistance and high magnetic permeability are two of ferrites' most significant characteristics.
- ✓ For equipment like antennas, high permeability to magnetic fields is especially desirable.
- ✓ To lessen eddy currents, transformer cores should have a high resistance to electricity.
- ✓ An electric current can magnetize ferrites of the square-loop ferrite type in one of two directions.
- ✓ Because of this characteristic, they can be used in the memory cores of digital computers, where a little ferrite ring can hold binary data.
- ✓ Certain single-crystal ferrites, in which microscopic magnetic domains known as bubbles may be individually, controlled, can be used to create a different kind of computer memory.
- ✓ Because certain ferrites only absorb microwave energy in one orientation or direction, they are utilized in microwave wave guides.

10.Applications of Ferrites:

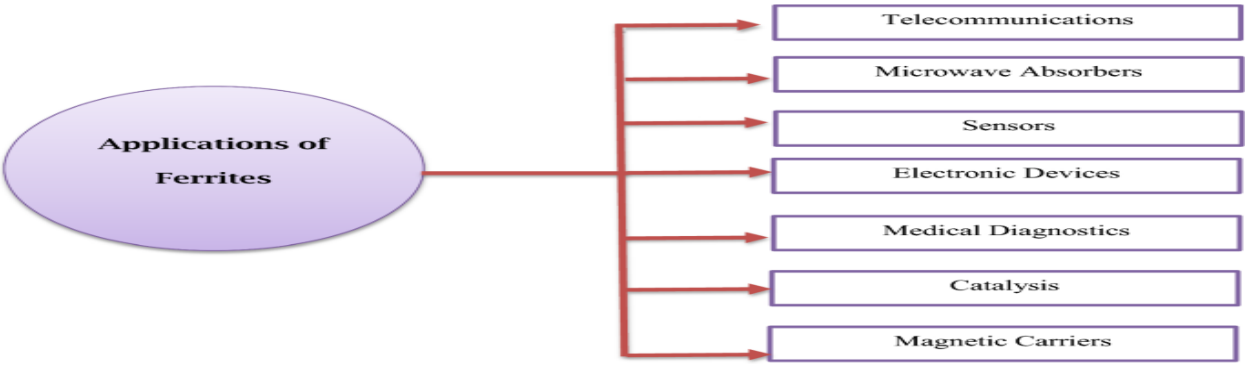

Fig.12: Applications of ferrites (68)

11. Future Scope of Ferrites

Lastly, I'd want to provide my opinions about ferrites' prospects for the future. Nobody questions that the production of amount ferrite will continue to rise annually, as previously mentioned, and that this trend will continue as electronic technologies progress. Future ferrites will enjoy a stable and more advanced prosperity in science and technology if ferrites-related researchers and engineers focus more on the future features of ferrites and dedicate their efforts to highly valuable themes.

12. Conclusion

Trivalent iron oxide combined with one or more bivalent oxides is known as a ferrite. While some of them are deviant in nature, the majority are stoichiometrically balanced, containing bivalent and ferric oxides in a 1:1 ratio. The key characteristics of ferrite materials are their strong magnetic property, comparatively low conductivity, low eddy current and dielectric losses, and high permeability. The various forms of ferrites exhibit distinct chemical compositions and configurations, which lead to differences in their characteristics that make them viable options for industrial, biomedical, and electrical use.

References:

1. E.C. Snelling, “Soft Ferrites, Properties and Applications”, first ed., Iliffe Books Ltd., London, 1969.
2. C.D. Owens, A survey of the properties and applications of ferrites below microwave frequencies,Proc. IRE 44 (1956) 1234e1248.
3. H.P.J. Wijn, Some remarks on the history of ferrite research in europe, in: Y. Hoshino, S. Iida,M. Sugimoto (Eds.), XixeXxiii in Proceedings of the International Conference on Ferrites (Kyoto,Japan, July 1970), University of Tokyo Press, Tokyo, Japan, 1971.
4. J.L. Snoek, New Developments in Ferromagnetic Materials, Elsevier, Amsterdam, The Netherlands,1947. Nanotechnology - Information from the Occupational Safety and Health Administration, part of the US Department of Labor
5. K. Kamala Bharathi, R.S. Vemuri, M. Noor-A-Alam, C.V. Ramana, Effect of annealing on the microstructure of NiFe1.925Dy0.075O4 thin films, Thin Solid Films 520 (2012) 1794e1798.
6. I. Boris, Kharisov, H.V. Rasika Dias, Mini-review: ferrite nanoparticles in the catalysis, Arab. J Chem.12 (2019) 1234. Alagarasi, A. (2009). Introduction to nanomaterials. In: Nanomaterials
(ed. B. Viswanathan), 2–25. Mumbai: Narosa Publishing House
7. U. € Ozg € ur, Y. Alivov, H. Morkoç, Microw. ferr., part 1: Fundam. prop.J. Mater. Sci.: Mater. Electr. 20 €(2009) 789e834.
8. M. Sugimoto, The past, present, and future of ferrites, J. Am. Ceram. Soc. 2 (1999) 269.
9 .J. Smit, H.P.J. Wijn, Ferrites: Physical Properties of Ferrimagnetic Oxides in Relation to Their Technical Applications, Philips’ Technical Library, Eindhoven, The Netherlands, 1959.
10. K.M. Krishnan, Introduction to Magnetism and Magnetic Materials, 2016, https://doi.org/10.1093/
acprof:oso/9780199570447.003.0001.

11. H. Shokrollahi, K. Janghorban, Influence of additives on the magnetic properties, microstructure and densification of MneZn soft ferrites, J. Mater. Sci. Eng. B. 141 (2007) 91e107. Namra Abid a Aqib Muhammad Khan b Sara Shujait a Kainat Chaudhary a Muhammad Ikram c Muhammad Imran d Junaid Haider e Maaz Khan f Qasim Khan g Muhammad Maqbool h

12. Q. Peng, J. Huang, M. Chen, Q. Sun, Phase-field simulation of magnetic hysteresis and mechanically induced remanent magnetization rotation in Ni-Mn-Ga ferromagnetic shape memory alloy, Scripta Mater. 127 (2017) 49.

13. J. Wallyn, N. Anton, T.F. Vandamme, Synthesis, principles, and properties of magnetite nanoparticles for in vivo imaging applicationsda review, Pharmaceutics 11 (2019) 601. https://doi.org/10.3390/pharmaceutics11110601.

14. R. Skomski, D.J. Sellmyer, Handb. Adv. Magn. Mater, Springer, US, Boston, MA, 2008, p. 1.

15. Ferrites, An introduction for microwave engineers, R.A. Waldron. Mathematics and System Analysis Laboratory Marconi’s Wireless Telegraph Company Great Baeldow, Essex, P. Van Nostrand Company LTD London, Toronto, new Tork, Princeton, new Jersey.

16. C. Heck, Magnetic Materials and Their Applications, Butterworths, London, 1974.48 Spinal Ferrite Nanostructures for Energy Storage Devices, Nanoparticle and Nanomaterial Applications: Biomedical Research; Health Care; Environmental Protection; Energy Sources; Agriculture and Food; Consumer Goods; Construction, Smart Cite; and Electronics, Machines. (top left corner, then clockwise).

17. D.H.K. Reddy, Y.-S. Yun, Spinel ferrite magnetic adsorbents: alternative future materials for water purification? Coord. Chem. Rev. Coord. Chem. Rev. 315 (2016) 90.

18. D.H. Taffa, R. Dillert, A.C. Ulpe, K.C.L. Bauerfeind, T. Bredow, D.W. Bahnemann, M. Wark,Photoelectrochemical and theoretical investigations of spinel type ferrites (MxFe3xO4) for water splitting: a mini-review, J. Photon. Energy 7 (2016), 012009.

19. V.D. Silva, L.S. Ferreira, T.A. Simoes, E.S. Medeiros, D.A. Macedo, 1D hollow MFe ~ 2O4 (M¼ Cu,Co, Ni) fibers by Solution Blow Spinning for oxygen evolution reaction, J. Colloid Interface Sci. 540(2019) 59. Saratale, 2018

20. K.K. Kefeni, B.B. Mamba, T.A.M. Msagati, Application of spinel ferrite nanoparticles in water and wastewater treatment: a review Sep, Purif. Technol. 188 (2017) 399.

21. N. Guijarro, P. Bornoz, M. Prevot, X. Yu, X. Zhu, M. Johnson, X. Jeanbourquin, F. Le Formal,K. Sivula, Evaluating spinel ferrites MFe2O4 (M¼ Cu, Mg, Zn) as photoanodes for solar water oxidation: prospects and limitations, Sustain. Energy Fuels 2 (2018) 103.

22. W.H. Bragg, The structure of the spinel group of crystals, Phil. Mag. 30 (1915) 305.

23. L.L. Hench, J.K. West, The sol-gel process, Chem. Rev. 90 (1990) 33.

24. H. Shokrollahi, Magnetic properties and densification of manganeseezinc soft ferrites (Mn1-xZnxFe2O4) doped with low melting point oxides, J. Magn. Magn Mater. 320 (2008) 463e474.

25. P.I. Slick, Ferrites for non-microwave applications, Handb. Magn. Mater. 2 (1980) 189.

26.J. Smit, F.K. Lotgering, P.P. VanStaple, Study of structural, magnetic and electrical properties of as prepared and gamma iradiated rare-earth doped nanoparticle ferrite material, J. Phys. Soc. Japan17B (1962) 158.

27. G. Hu, J.H. Choi, C.B. Eom, V.G. Harris, Y. Suzuk, Structural tuning of the magnetic behavior inspinel-structure ferrite thin films, Physiol. Rev. B 62 (2000) 779.
28. E.J.W. Verwey, E.L. Heilman, Physical properties and cation arrangement of oxides with spinel structures I. Cation arrangement in spinels, Chem. Phys. 15 (1947) 174.
29. K.J. Standley, Oxide Magnetic Materials, second ed., Oxford University Press, 1972, p. 254.
30. G. Litsardakis, I. Manolakis, C. Serletis, K.G. Efthimiadis, Effects of Gd substitution on the structural and magnetic properties of strontium hexaferrites, J. Magn. Magn Mater. 316 (2007) 170.
31. R.C. Pullar, Hexagonal ferrites: a review of the synthesis, properties and applications of hexaferrite ceramics, Prog. Mater. Sci. 57 (2012) 1191.
32. A.L. Stuijts, G.W. Rathenau, G.H. Weber, Ferroxdure I and II, anisotropic permanent magnet materials, Philips Tech. Rev. 16 (1954) 141.
33. V.G. Harris, Microwave Ferrites and Applications, Microwave Materials and Applications, second ed.,John Wiley & Sons, Ltd, 2017. Published.
34. K.B. Modi, P.Y. Raval, P.R. Pansara, I.R. Badi, D.R. Devmurari, S.S. Munshi, P.U. Sharma, On the relationship between structural-optical parameters of Y3xFe5þxO12 garnet ferrites and the oxide additivity rule, J. Supercond. Nov. Magnetism 29 (2016) 1931.
35. M.N. Akhtar, A.B. Sulong, M. Ahmad, M.A. Khan, A. Ali, M.U. Islam, Impacts of GdeCe on the structural, morphological and magnetic properties of garnet nanocrystalline ferrites synthesized via solegel route, J. Alloys Compd. 660 (2016) 486.
36. S. Geller, M.A. Gilleo, The crystal structure and ferrimagnetism of yttrium-iron garnet, Y3Fe2 (FeO4)3, J. Phys. Chem. Solid. 3 (1957) 30.
37. T. Nakajima, Y. Tokunaga, Y. Taguchi, Y. Tokura, T. Arima, Piezomagnetoelectric effect of spin origin in dysprosium orthoferrite, Phys. Rev. Lett. 115 (2015) 197205.
38. A.H.M. Reid, T. Rasing, R.V. Pisarev, H.A. Durr, M.C. Hoffmann, Terahertz-driven magnetismdynamics in the orthoferrite DyFeO3, Appl. Phys. Lett. 106 (2015) 082403.
39. G.H. Jonker, J.H. Van Santen, Ferromagnetic compounds of manganese with perovskite structure,Physica 16 (1950) 337e349.
40. R.G. Kulkarni, Role of magnetic moment on superconductivity in (Rw 1w-w xHfw x)Baw 2Cuw 3Ow z (R¼ Er, Y), Asian J. Phys. 6 (1997) 204. Safia Anjum Jazaria Fayyaz Rabia Khurram Rehana Zia December 2018.
41. D. Stoppels, Relationship between magnetocrystalline anisotropy, including second-order contribution, and initial magnetic permeability for monocrystalline MnZn ferrous ferrite, J. Appl. Phys. 51
(1980) 2789.
42. A. Broese van Groenou, P.F. Bongers, A.L. Stuyts, Magnetism, microstructure and crystal chemistry ofspinel ferrites, Mater. Sci. Eng. 3 (1968e1969) 317e392.Properties of ferrites 49
43. R. Rangnathan, A. Ray, Ferrites d what is new? Pramana 58 (2002) 995. Vijaykumar V. Jadhav, Rajaram S. Mane & Pritamkumar V. Shinde 16 May 2020
44. M. Sugimoto, The past, present, and future of ferrites, J. Am. Ceram. Soc. 82 (1999) 269.
45 .Z. Ullah, S. Atiq, S. Naseem, Influence of Pb doping on structural, electrical and magnetic properties of Sr-hexaferrites, J. Alloys Compd. 555 (2013) 263.

46. L. Neel, Proprietees magnetiques des ferrites, Ferrimagnetisme et antiferromagnetisme Ann. phys 12(3) (1948) 137e198.
47. J.J. Went, E.W. Gorter, The magnetic and electrical properties of ferrite materials, Philips Tech. Rev.13 (1952) 181e193.
48. D.L. Leslie-Pelecky, R.D. Rieke, Magnetic properties of nanostructured materials, Chem. Mater. 8(1996) 1770e1783.
49. J. Smit, H.P.J. Wijn, Ferrites, Philips’ Technical Library, Eindhoven, The Netherlands, 1959.
50. E.W. Gorter, Some properties of ferrites in connection with their chemistry, Proc. IRE 43 (1955)1945 ff.
51. J. Smit and H. P. J. Wijn, Physical properties of ferrites. Adv. Electron. Electron. Phys. 6, 69-136. IndiaMART > Bar, Neodymium & Permanent Magnets > Electromagnets > Soft Ferrites.
52. J. Smit, H.P.J. Wijn, Ferrites, Wiley, New York, 1959.
53. H.P.J. Wijn, E.W. Gorter, C.J. Esveldt, P. Geldermans, Conditions for square hysteresis loops in ferrites, Philips Tech. Rev. 16 (2) (1954) 49. IndiaMART > Bar, Neodymium & Permanent Magnets > Electromagnets > Soft Ferrites.
54. E. Ross, I. Hanke, E. Moser, Ferrites with initial permeability exceeding 20 000 and theirmicrostructures, Z. Angew. Phys. 17 (1964) 504.
55. D.J. Perduijn, H.P. Peloschek, MnZn ferrites with very high permabilities, Proc. Br. Ceram. Soc. 10(1968) 263.
56. E.G. Visser, M.T. Johnson, P.J. van der Zaag, Proceedings of the 6th International Conference onFerrites (ICF-6), The Japanese Society of Powder and Powder, Metallurgy, Tokyo, 1992.
57 .H.P.J. Wijn, Ph.D. Thesis., 1953. Leiden.
58. B.D. Cullity, Introduction to Magnetic Materials, Addison-Wesley Publishing Company, Reading,MA, 1972.
59. S. Chikazumi, Physics of Magnetism, John Wiley & Sons, Inc., New York, 1978. IndiaMART > Bar, Neodymium & Permanent Magnets > Electromagnets > Soft Ferrites.
60. K. Ohta, N. Kobayashi, Magnetostriction constants of Mn-Zn-Fe ferrites, Jpn. J. Appl. Phys. 3 (1964)576.
61.M. Noda, Y. Okazaki, K. Hara, K. Ogisu, IEEE Trans. Magn. MAG26 (1990) 81.62. A.L. Stuyts, G.W. Rathenau, G.H. Weber, Ferroxdure II and III, anisotropic permanent magnet materials, Philips Tech. Rev. 16 (5/6) (1954) 141. IndiaMART > Bar, Neodymium & Permanent Magnets > Electromagnets > Soft Ferrites.