

## A RESEARCH ON A COMPARATIVE STUDY OF CHARACTERIZATION OF STRONTIUM NANO FOR MICROWAVE APPLICATION

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### Abstract

"There is lots of room down the bottom," Richard Feynman began a 1959 annual conference. He said that we can do miracles if we can control things at a lower level. It revolutionized material science and spurred serious research. Nanotechnology is vital for cutting-edge materials. Magnetism and magnetic materials underpin fast growing electronics engineering material technologies. Nanotechnology makes materials nanoscale. Nanoscale magnetic materials have superior electric and magnetic characteristics. This study examines how structural, morphological, electrical, magnetic, and microwave features affect doping ion concentration.

This study examines how replacing  $Tb^{2+}$  ions for  $Sr^{2+}$  ions affects all of the properties. Terbium substituted strontium hexaferrite ( $TbxSr_{1-x}Fe_{12}O_{19}$ ) nanoparticles were formed from chloride salts and 10 M NaOH (sodium hydroxide solution). These materials are ideally calcined at 8000C. JCPDS data showed that all strontium hexaferrite samples, pure and doped with terbium, exhibited hexagonal crystallite diameters of 49 to 85 nm. Terbium ions replaced pure SrM, changing magnetic properties (strontium hexaferrite). High Hc values of 5126 KOe for pure strontium hexaferrite and 5548–4496 KOe for terbium-doped ones demonstrate its harsh magnetic character.

Dielectric characterisation pellets were made from powdered material. Dielectric constant, loss, and loss tangent were investigated. Terbium-doped strontium hexaferrite has a higher dielectric loss tangent than pure strontium. Green pellets were heated at 11000°C, 1200°C, and 13000°C for 30 minutes for higher frequency characterization. Three-dimensional growth and continual

nucleation accelerate transformation during heat treatment. At ambient temperature, dielectric characteristics between 100 Hz and 1 MHz were assessed again. The dipole relaxation is inversely related to frequency because the cation state changes from  $Fe^{3+}$  to  $Fe^{2+}$ . High-frequency dielectric loss reduction.

Dielectric and microwave properties up to 6 GHz were studied. Samples showed nonlinear relative permittivity at specific frequencies. Microwave study showed a 4–21 dielectric constant variation. The material may shrink antennas after assessing all characterization methods. The thesis simulates two-antenna designs of pure and doped strontium nano hexaferrite with different dielectric constants.

### INTRODUCTION

The study of phenomena that lead to changes in the characteristics of a material that vary expressively as a result of manipulation at the atomic, molecular, and submolecular levels of a material is what is known as nanoscience.

Nanotechnology may be defined as the controlled manipulation (at atomic, molecular, and macromolecular scales) of form and size at the nanometric scale for the purpose of designing, characterizing, producing, and applying structures, devices, and systems that have at least one unique property.

Both the field of nanoscience and the field of nanotechnology have the prefix "nano,"

which comes from the Greek word for "dwarf." The unit of measurement known as a nanometer (abbreviated as "nm") is equivalent to  $10^{-9}$  of a meter. When compared to the width of a human hair, which is around 1/80,000 nm, one may begin to comprehend how minute the word "nano" really is in terms of its dimensions. During his speech in 1959 titled "There's Plenty of Room at the Bottom," Richard Feynman theoretically lay the groundwork for what would later become known as nanotechnologies.

He examined whether or not it was possible to exert control on material on the scale of molecules and atoms. Even up until 1974, the term "nanotechnology" was not commonly used. It was not until Taniguchi, a researcher at the University of Tokyo in Japan, coined the term to describe the capacity of science to examine and control material at a level below the metric system that the term entered common usage. Nanotechnology makes it possible to create materials and technologies of a new generation, making them applicable to a wide variety of fields and industries, including nanoelectronics, nanomedicine, consumer goods, and biomaterial energy products.

The progression of steel from the advanced materials of the 19th century to those of the 21st century has resulted in the ability to manipulate, control, and construct structures on a very small scale. It eventually turned out to be the deciding factor in the creation of new materials. Additionally, miniaturization in the electronic sector, which included the placement of devices on silicon chips, was a pull factor that contributed to the shrinking of the material. These newly

downsized materials have the potential to pave the way for the development of nanostructures and systems that are more complex.

The rate of increase in the number of products containing such nanomaterials and the number of possible applications for these nanomaterials continues to grow at an exponential rate. This is due to the fact that new uses for materials that have these improved properties are being discovered and explored. There is still a compelling need for a system-oriented interdisciplinary approach to be able to manufacture nano materials and devices that have features that are unique to themselves.

### **Nanomaterials**

Despite the fact that a large number of nanomaterials are still in the research and development phase, a few of them are beginning to see use in consumer products. The development of nanoscience and nanotechnologies has the potential to be used in a variety of fields in the not too distant future. Because of the way in which they behave as a scaffold between bulk materials and atomic level molecules, these nanostructured materials have piqued the interest of the scientific community. The characteristics of nanomaterials are fundamentally distinct from those of other materials for two primary reasons, both of which are explained in more detail below.

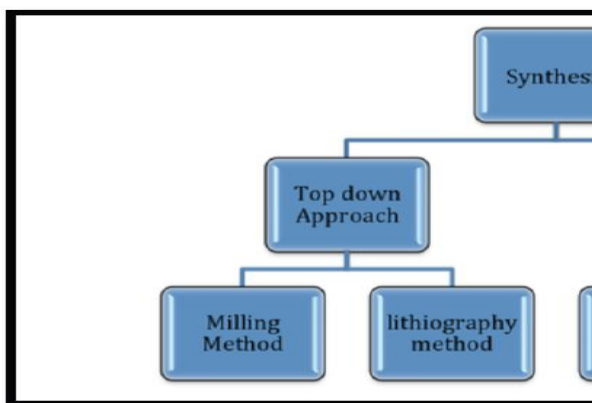
- Surface to Volume Ratio
- Quantum effect.

A material's reactivity, strength, and electrical properties may all be improved by include these elements in its composition. When the size of the particle is lowered to nanoscale, quantum effects,

in conjunction with surface-area effects, may begin to dominate the characteristics of the matter. When the size reaches the lower range of the nanoscale, these effects have the potential to change the electrical, magnetic, and optical characteristics of a material on a wider scale. The structure of a material at the micro and nanoscales is helpful in establishing the overall qualities of a material's constituent parts, including paints and silicon chips, for example.

### SYNTHESIS AND CHARACTERIZATION OF FERRITES

A key factor in controlling particle size in the nanoscale region is the synthesis of nanomaterials (1 to 100 nm). The substances meeting this requirement are known as nano materials. For the synthesis of nanomaterials and -structures, top down approach and bottom up approach are often used. Any technique used to create nanomaterials has the goal of giving the material the required properties. The process for making nanomaterials aims to produce distinctive lengths between 1 and 100 nm in the nanometer range.



Synthesis of Nano Materials

### Synthesis of Pure and Terbium Doped Strontium Nano-Hexaferrite

According to a study of the research that has been done, the procedure of

synthesising nanomaterials plays an essential function in the process of manipulating particle size in the nano scale range (1 to 100 nm). Nano particles are the collective name for the types of substances that meet this requirement. For the synthesis of nanomaterials and -structures, two different overarching strategies have been used. In this endeavor, we are approaching things from the bottom up.

There are many different methods for the synthesis of nanomaterials utilizing a bottom-up approach. Some examples of these methods are the sonochemical method, the sol gel method, ball milling, chemical co-precipitation, and hydrothermal. However, in the course of our research, we chose to manufacture terbium-doped strontium hexaferrite by the chemical co-precipitation approach. This was done in order to improve the characteristics of nano hexaferrite.

"Co-precipitation is a process in which a solute that would normally stay dissolved in a solution precipitates out on a carrier," according to one definition of the term. This carrier makes it such that it cannot continue to be distributed and instead compels it to join together. Even though it is an undesired chemical reaction, it is possible for this to take place both in natural settings and in laboratory conditions.

#### 4.2.1 Experimental Work Done

Nanocrystals of terbium-doped strontium hexaferrite were created at the Nanotechnology Research Laboratory of Chitkara University in Punjab by using a wet chemical co-precipitation process. Because of the inherent benefits of being simple and user pleasant, all of the synthesis was performed in aqueous solutions at room temperature and under

ambient conditions.

Following the verification of the XRD findings of the samples, the concentration of the dopant was decided to be between 2% and 10%. This decision was made based on the finding that the crystallite size increased to be more than 100 nm if the concentration of the dopant was increased over 10%.

The composition, crystal structure, and state of the ferrites, as well as the manner of their manufacture, all have an effect on their properties. The aim statements led to the decision to use the chemical co-precipitation approach for the production of nanoferrites in this particular piece of work. The following characteristics are associated with this method:

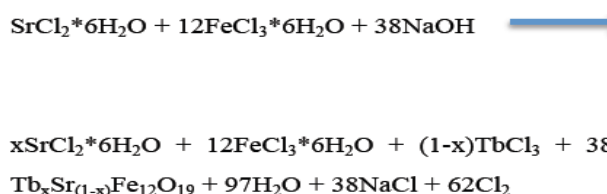
- It uses the bottom-up technique, which refers to the manipulation of materials at the atomic and molecular level in order to generate nanostructures (as shown in fig 4.1).
- Both the nucleation and the growth processes take occur concurrently during this procedure.

**Sample preparations:**

The powder samples were produced by beginning with precursors in the form of chlorides and working backwards through the synthesis process.

**Chemical Equation**

Ph=12



The chemical substances that are going to be employed for the experimental work are purchased from a reputable supplier.



**Titration (a)**



**Filtration (b)**



**Hot Air Oven set at a temp of 100°C (d)**



**After heating at 100°C in muffle furnace (e)**

**4.2.1 X-Ray Diffraction Analysis (Results & Discussions)**

X-ray diffraction is used both for structural analysis and to find out how the atoms in a material are arranged in three dimensions. Calcination of the synthesized powder has taken place at a variety of temperatures; the XRD findings have been analyzed and verified, and this has led to the selection of the most effective temperature.

The powder that was produced after being synthesized was calcined at three distinct temperatures, namely 4,000 degrees Celsius, 6,000 degrees Celsius, and 8,000 degrees Celsius, respectively. The powder that was produced after this process was then characterized.

PAN analytical X-ray (X-PERT PRO), which has  $\lambda = 1.54 \text{ \AA}$  for CuK and a scan rate of  $0.0170^\circ/\text{sec}$ , was used to perform structural analysis and the identification of the phase. This was accomplished with the help of the machine. The range of the scattering angle, will now vary from 20 degrees all the way up to 80 degrees.

**Microwave Properties (Results & Discussions)**

The samples that were sintered at



temperatures of 11,000 degrees Celsius, 12,000 degrees Celsius, and 13,000 degrees Celsius all had their microwave characteristics analyzed. Six separate samples, each with a doping level ranging from 0 to 10% and a change of 2%, have been subjected to each of the three temperature ranges, resulting in a total of six times three, or eighteen unique samples.

At the microwave material testing facility of keysight technologies in New Delhi, the samples were tested in order to study these qualities. VNA with a frequency range of 1 GHz to 6 GHz was used. In our research, the nomenclature for a sample of pure strontium hexaferrite is denoted by the letter SP, and the nomenclature for a sample of doped strontium hexaferrite with different concentrations from (x= 0.02 to 0.10.0) is denoted by the letters S1 to S5 accordingly.

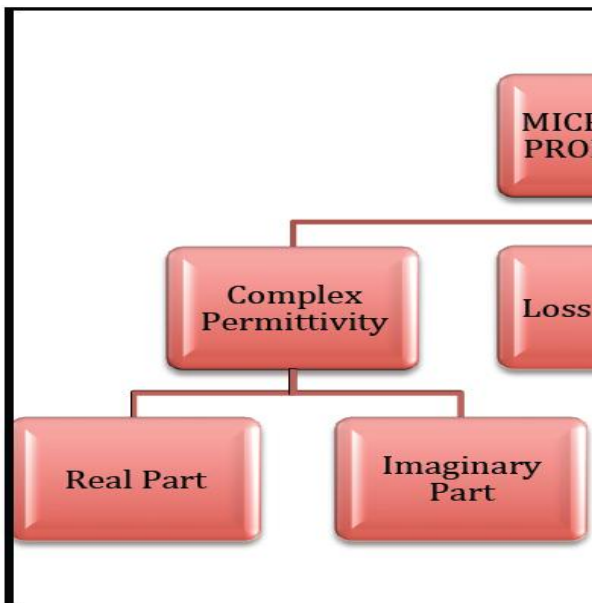
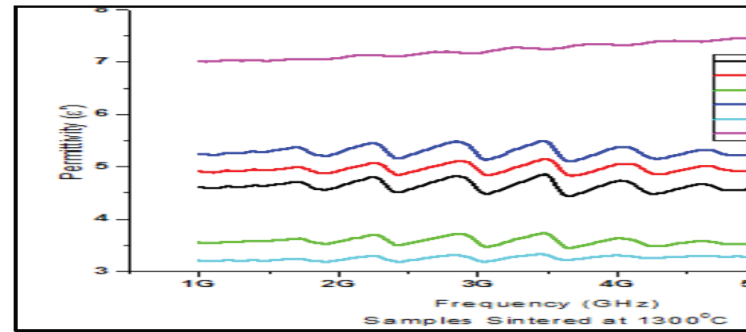


Figure- shows the parameters that have been studied in order to investigate microwave properties.



This drop in dielectric permittivity is particularly pronounced at lower frequencies as compared to higher frequencies, where it is rather steady. A dielectric behavior of Magnetoplumbite's at higher frequencies similar to the one seen by the current material might be anticipated to display itself at these frequencies.

The theory proposed by Rabinkin and Novikova, according to which the polarization in ferrites occurs by a mechanism that is quite similar to the process of conduction, may provide an explanation for the fact that the dielectric constant does not vary as a function of frequency.

The reason for the decreases in polarization with respect to frequency and why they remain constant at giga hertz range is because the exchange of ions between  $Fe^{2+}$  and  $Fe^{3+}$  cannot follow the rate of change of the external field when it is at microwave frequency. This is the cause of the phenomenon known as microwave frequency polarization. The very high values of  $\epsilon'$  at lower frequencies arise as a result of the prevalence of species such as interfacial dislocation pile-ups, oxygen vacancies, grain boundary defects, and other similar phenomena.

### Conclusion

in-depth examination of both unadulterated strontium hex aferrite and strontium hex aferrite that has been doped with terbium.

These materials were made using the chemical approach of co-precipitation in the preparation process. This synthesis approach produces the appropriate yield of material in nano form, and as a result, it demonstrates that it is an effective method for the creation of strontium hex aferrite. In order to conduct the comparative investigation of pure and terbium-doped strontium hex aferrite, a number of different approaches for characterizing materials have been used.

The influence that the synthesis procedure has on the physiological qualities of ferrites is also illustrated in this study. X-ray diffraction, Fourier transform infrared absorption, and transmission electron microscopy have been used in this research to investigate the structural and morphological characteristics of pure and terbium-doped strontium hex aferrite, respectively. Studies have also been conducted on the DC magnetic characteristics such as saturation magnetization; coercivity; remanence; and magneto crystalline anisotropy.

Both of these materials have had their electrical characteristics analyzed, including their ac conductivity, dielectric permittivity, loss tangent, and dielectric loss. Using a variety of microwave testing methods, the intrinsic characteristics of SrM and TbSrM ferrites, such as conductivity, permittivity, and return loss, have been researched in order to evaluate the possibility of their usage as magneto dielectric material in the frequency range of 1 to 6 GHz. The following is a report that provides a concise summary of all of the results from the research on the synthesis and characterisation of pure and terbium-doped strontium hex aferrite.

Synthesis of strontium hex aferrite

nanomaterial was facilitated by the chemical co-precipitation method, which was shown to be both an effective and straightforward approach. The results of the XRD analysis demonstrate the emergence of a mono phase pattern in samples of SrFe<sub>12</sub>O<sub>19</sub> and Sr<sub>1-x</sub>(Tb)<sub>x</sub>Fe<sub>12</sub>O<sub>19</sub> (x =0.02, 0.04, 0.06, 0.08, and 0.10). This pattern shows the samples' transition from an amorphous structure to a crystalline structure in nano form. According to the findings of the XRD analysis, the average crystallite size of both pure and doped samples ranges from 49 to 85 nanometers, which is in agreement with the standard reference. When terbium is added up to a concentration of 6%, the particle size initially grows, and then it begins to progressively decrease as the dopant concentration continues to be increased up to a concentration of 10%.

The creation of the phase of the particle is dependent, first, on the even distribution of the metal ions throughout the solution and, secondarily, on the temperature of the calcination process. It has been determined that a calcination temperature of 8000 degrees Celsius produces the best results when used to this particular synthesis method. This optimization of the calcination temperature was performed in order to get the nano ferrites with the ideal size. The transmission electron micrographs that are provided in this study demonstrate that particles with mean sizes ranging from 2 nm to 120 nm have a morphology that is characteristically hexagonal and plate-like. In the case of terbium-doped samples, the addition of interfacial surface tension has been seen to cause the particles to agglomerate, and this may be deduced from the micrographs of

the transmission electron microscope (TEM). The findings of the XRD and TEM analyses show that the synthesized strontium hexaferrite has a smaller crystallite size than other ferrite materials, which indicates that it is an improved ferrite material for usage at higher frequencies.

In the current study, investigations into the magnetic, dielectric, and microwave characteristics of the synthetic material have been carried out. After introducing Tb ions into pure SrM, there was a discernible shift in the material's magnetic characteristics. The replacement of Tb ions results in a significant reduction in the remanence, whereas only a little shift in the coercivity is seen. Under the influence of a magnetic field of 15 KOe, the magnetization curve of Sr<sub>1-x</sub>(Tb)<sub>x</sub>Fe<sub>12</sub>O<sub>19</sub> (x = 0.02, 0.04, 0.06, 0.08, and 0.1) revealed ferromagnetic characteristics that had been saturated. In addition to this, it reveals that the remanent magnetization (Mr) and saturation magnetization (Ms) are getting closer to the values of 24.2 and 50 emu/g, respectively. In compared to prior efforts, these hexagonal ferrites have increased saturation magnetization and greater coercivity, which positions them as an excellent candidate for use as a material in magnetic devices and as a material capable of absorbing electromagnetic waves.

Microwave electromagnetic characteristics of doped strontium hexaferrite have been explored in the microwave frequency band (1-6 GHz), together with their performance as microwave absorbing and shielding materials. This research was carried out in conjunction with the microwave frequency band. For the purpose of characterization of terbium substituted strontium

hexaferrite Sr<sub>1-x</sub>(Tb)<sub>x</sub>Fe<sub>12</sub>O<sub>19</sub> (x = 0.02, 0.04, 0.06, 0.08, and 0.10), a vector network analyzer was utilized. The material in question was synthesized by means of chemical co-precipitation, and it was sintered at three distinct temperatures: 11,000 degrees Celsius, 12,000 degrees Celsius, and 13,000 degrees Celsius. Only in the scenario when the samples were sintered at 11000C did the dielectric permittivity range from 4 to 9. This was the case for all of the synthetic samples that were sintered at 12000C and 13000C. The permittivity was anywhere from 4.2 to 22 on the scale.

The dielectric permittivity has shown only very little shifts up to a terbium substitution level of 6 percent. Additionally, samples sintered at 12000 degrees Celsius with 6% terbium doping perform very well and are suitable for use in absorption applications. The terbium doping in the strontium hexaferrite allowed for the production of materials that reflected up to around 88% of the electromagnetic energy. Providing evidence that these materials are capable of being used as electromagnetic wave shielding materials. As a result of this comparison, it has become abundantly evident that the samples sintered at 13,000 degrees Celsius are superior to the other ones as electromagnetic shielding materials. Therefore, the terbium-doped strontium hexaferrite nanomaterial that was created demonstrates that it is capable of functioning as a microwave absorber at high frequency.

Additionally, these components, in varying concentrations, might be used into the design of microwave devices to facilitate further development in the area of microwave technology. In addition to this,

the relationship between absorption and sintering temperature has been found. It has been noticed that the loss tangent rises as the concentration of terbium as a dopant in strontium hex ferrite samples rises. This is the case when the sample contains more terbium. Because of the rise in dielectric constant and rise in loss tangent that accompany an increase in terbium concentration, materials containing terbium are well-suited for use in high-frequency applications. Therefore, the terbium doped strontium hexaferrite nano material that was created demonstrates that it is capable of functioning as a microwave absorber at high frequency. For the purpose of furthering research and development in the area of microwave technology, these materials might be used into the design of microwave devices.

Additional research into the use of these materials in antenna design has been conducted. The dielectric permittivity of the downsized antenna was intended to be between 4.8 and 8.2 respectively. In the former scenario, improved bandwidth and lower directivity, both of which are desired for use in Wi-Fi applications, have been observed. When compared to the antenna that used FR4 and RT5880 as substrate material, the dimensions of the antenna that used SrM and TbSrM as a substrate were found to be 28% smaller than those of the antenna that used FR4 and RT5880. In addition, when utilizing TbSrM as the substrate material, both efficiency and directivity are enhanced, while the VSWR is maintained at an acceptable level of less than one, indicating that losses are kept to a minimal. Antennas made of pure or doped strontium manganate may be used for Wi-Fi networks. The simulations were run using CST microwave studio 2010,

which was used to do the tests.

## References

1. K. E. Drexler, "Engines of creation - The Coming Era of Nanotechnology," Anchor Books-Doubleday, vol. 1986, pp. 576, 2006.
2. R. P. Feynman, "There's Plenty of Room at the Bottom," *Eng. Sci.*, vol. 23, no. December, pp. 22–36, 1960.
3. N. Taniguchi, "The Japan Society for Precision Engineering," *Basic Concept 'Nanotechnology. Proc. Int. Conf. Prod. Eng.*, pp. 18–23, 1974.
4. B. Bhushan, *Springer Handbook of Nanotechnology. Nanotribology Laboratory for Information Storage and MEMS/NEMS USA Library*, pp. 1167, 2004.
5. A. Wu, P. Ou, L. Zeng, "Biomedical Applications of Magnetic Nanoparticles," *Nano*, vol. 5, no. 5, pp. 245–270, 2010.
6. M. S. Diallo, N. A. Fromer, and M. S. Jhon, "Nanotechnology for sustainable development, first edition," *Nanotechnol. Sustain. Dev. First Ed.*, pp. 1–401, 2014.
7. K. Kim, K.W. Jeon, K. W. Moon, M. K. Kang, and J. Kim, "Effects of Calcination Conditions on Magnetic Properties in Strontium Ferrite Synthesized by the Molten Salt Method," *IEEE Trans. Magn.*, vol. 52, no. 7, pp. 1–4, 2016.
8. D. Gann, *A Review of Nanotechnology and Its Potential Applications for Construction*. SPRU, University of Sussex, 2002.
9. R.W. Whatmore and J. Corbett, "Nanotechnology in the Marketplace," *Comput. Control J.*, pp. 105–107, 1995.
10. W.I. Atkinson, *Nanocosm— Nanotechnology and the Big Changes Coming from the Inconceivably Small*; pp. 36–39. AMACOM, 2004.
11. C.P. Poole and F.J. Owens, "Introduction to Nanotechnology", Wiley, New York, 2003.
12. K.J. Klabunde (Ed.), *Nanoscale Materials in Chemistry*. Wiley, New York, 2001
13. M. C. Roco, C. A. Mirkin, and M. C. Hersam, "Nanotechnology research directions for societal needs in 2020: summary of international study," *J. Nanoparticle Res.*, vol. 13, no. 3, pp. 897–919, Mar. 2011.
14. D.V. Smitherman Jr. (Ed), "Space Elevators: An Advanced Earth–Space Infrastructure for the New Millennium," *NASA/CP-2000-210429*, 2000.
15. M.C. Roco, R.S. Williams and P. Alivisatos (Eds.), "Vision for Nanotechnology R&D in the



Next Decade," IWGN Report on Nanotechnology Research Directions, National Science and Technology Council, Committee on Technology, 1999.

15. G. Guisbiers, "Size-dependent materials properties toward a universal equation," *Nanoscale Res. Lett.*, vol. 5, no. 7, pp. 1132–1136, 2010.

16. K. Sellers, "Nanotechnology and the environment". Boca Raton: CRC Press, 2009.

17. D. Aarhus U. Sutherland and L. Filipponi, "Fundamental concepts in nanoscience and nanotechnology," no. January, pp. 1–24, 2010.

18. B. Zhang, H. Misak, P. S. Dhanasekaran, D. Kalla, and R. Asmatulu, "Environmental Impacts of Nanotechnology and Its Products," *Am. Soc. Eng. Educ.*, pp. 1–9, 2011.

19. K. Borgohain, J. B. Singh, M. V Rama Rao, T. Shripathi, and S. Mahamuni, "Quantum size effects in CuO nanoparticles," *Phys. Rev. B*, vol. 61, no. 16, pp. 1109–1116, Apr. 2000.

20. F. Yang, D. Deng, X. Pan, Q. Fu, and X. Bao, "Understanding nano effects in catalysis," *Natl. Sci. Rev.*, vol. 2, no. 2, pp. 183–201, 2015.

21. Y. C. Huang, C. P. Chang, and M. F. Lin, "Magnetic and quantum confinement effects on electronic and optical properties of graphene ribbons," *Nanotechnology*, vol. 18, no. 49, pp.182-191, 2007.

22. E. Roduner, "Size matters: why nanomaterials are different," *Chem. Soc. Rev.*, vol. 35, no. 7, pp. 583–592, 2006.

23. P. V Patil, S. Datta, and P. V Patil, "Do we need to revisit the Bohr exciton radius of hot excitons?," *Sci. Educ.*, p. 39, 2011.

24. E. Eleftheriou, V. Tsakaloudi, and G. Kogias, "New high-frequency hexagonal ferrite materials i) 900 MHz RFID Antennas ii) 94 GHz non-reciprocal switches E.," *IEEE Antennas Wirel. Propag. Lett.*, no. 1, pp. 1–4, 2009.

25. P. E. Kazin, L. A. Trusov, D. D. Zaitsev, and Y. D. Tretyakov, "Glass crystallization synthesis of ultrafine hexagonal M-type ferrites: Particle morphology and magnetic characteristics," *Russ. J. Inorg. Chem.*, vol. 54, no. 14, pp. 2081–2090, 2009.

26. T. Tatarchuk, M. Bououdina, J. J. Vijaya, and L. J. Kennedy, "Nanophysics, Nanomaterials, Interface Studies, and Applications," vol. 195, pp. 305–325, 2017.

27. K. Harigaya, "The mechanism of magnetism in stacked nanographite: theoretical study," *J. Phys. Condens. Matter*, vol. 13, no. 6, p. 1295, 2001.

28. Richard M Bozorth "Ferromagnetism" Wiley-VCH, pp 1-992, August 1993.

29. J. L. Snoek "Dispersion and Absorption in Magnetic Ferrites at Frequencies" *Physica nature international journal of science*, Vol. 14, No. 4, pp-207-217, 1948.

30. L. Néel, (1955) "Some Theoretical Aspects of Rock Magnetism," *Adv. Phys.* 4, pp- 191-242.

31. L. R. Maxwell and S. J. Pickart, "Magnetization in Nickel Ferrite-Aluminates and Nickel Ferrite-Gallates," *Phys. Rev.*, vol. 92, no. 5, pp. 1120–1126, Dec. 1953.

32. "Heinrich Hertz's Laboratory Notes of 1887." Edited by H. Gerhard Hertz and Manuel Doncel. *Archive for History of Exact Sciences* 49 (1995): pp. 197–270, 1995.

33. V. G. Harris, A. Geiler, Y. Chen, S. D. Yoon, M. Wu, A. Yang, Z. Chen, P. He, P. V. Parimi, X. Zuo, C. E. Patton, M. Abe, O. Acher, and C. Vittoria, "Recent advances in processing and applications of microwave ferrites," *J. Magn. Mater.*, vol. 321, no. 14, pp. 2035–2047, 2009.

34. F. Cardarelli and F. Cardarelli, "Materials Handbook," 2008.