NANOSCALE INSIGHTS INTO THE STRUCTURAL AND MAGNETIC PROPERTIES OF CHROMIUM FERRITE

[1]Rajesh,[2]Sravanthi
[12]Students
Department of Basic Sciences & Humanities

ABSTRACT

Chromium ferrite ($CrFe_2O_4$) nanoparticles have garnered significant attention due to their unique magnetic and structural properties, making them promising candidates for applications in data storage, catalysis, magnetic sensors, and biomedical devices. This study explores the synthesis, structural characterization, and magnetic behavior of chromium ferrite nanoparticles prepared via the sol-gel auto-combustion method. X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), and transmission electron microscopy (TEM) were employed to determine the crystal structure, phase purity, and morphology of the synthesized nanoparticles. Vibrating sample magnetometry (VSM) was used to analyze their magnetic characteristics. The results confirmed the formation of a single-phase spinel structure with nanocrystalline features and exhibited typical ferrimagnetic behavior with size-dependent saturation magnetization and coercivity. These findings contribute to a deeper understanding of the structure–property relationship at the nanoscale and support the further development of $CrFe_2O_4$-based functional materials for high-performance technological applications.

I. INTRODUCTION

Nanostructured ferrites, particularly those with a spinel crystal structure, have emerged as critical materials in modern technology due to their tunable magnetic, electrical, and catalytic properties. Among them, chromium ferrite ($CrFe_2O_4$) has drawn increasing research interest owing to its inherent ferrimagnetic nature, chemical stability, and structural versatility. When synthesized at the nanoscale, these materials exhibit quantum-size effects and surface phenomena that significantly alter their macroscopic behavior, making them suitable for a wide array of functional applications—from magnetic storage media and microwave devices to drug delivery systems and magnetic refrigeration.

Understanding the structural and magnetic behavior of $CrFe_2O_4$ nanoparticles is essential for tailoring their properties for specific uses. Parameters such as crystallite size, cation distribution, surface area, and synthesis route greatly influence the final properties of the nanoparticles. In particular, the magnetization dynamics and coercive forces are highly sensitive to structural imperfections and particle morphology, making advanced characterization vital.

This study aims to provide a comprehensive analysis of chromium ferrite nanoparticles synthesized via the sol-gel auto-combustion method, focusing on their structural phase formation and magnetic behavior. The research investigates how nanoscale features affect the material's performance, contributing to the broader field of nano-engineered magnetic materials.

II. EXPERIMENTAL

The sample of $CrFe_2O_4$ spinel ferrite was prepared by wet chemical co-precipitation technique. The details of synthesis method have been discussed in our previous reports.[17] The structural characterization was made through X-ray diffraction technique in the 2□ range of 20^0 - 80^0. The XRD pattern was recorded at room temperature using Cr-$K\alpha$ λ=1.521 A^0 radiation. Microstructural studies including evaluation of a particle size were conducted using a JEOL – JS scanning electron microscope. The magnetic measurements were carried out at room temperature using pulse field magnetic hysteresis loop tracer.

III. RESULTS AND DISCUSSION

Structural Analysis

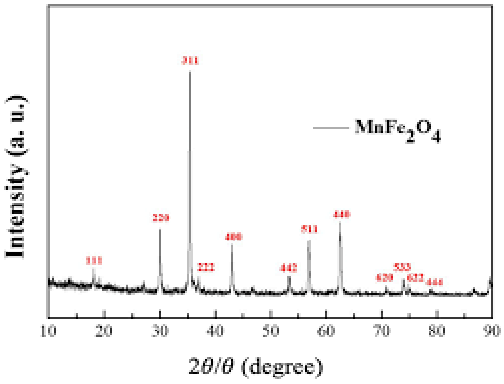

Fig.1: X-ray Fig.1 shows the X-ray diffraction (XRD) pattern of $CrFe_2O_4$ nanoparticles.

All the Bragg reflections have been indexed, which confirms the formation of cubic spinel structure in single phase. Bragg's reflections are found to be sharp and intense. The values of lattice parameter calculated from interplanar spacing (d) values and Miller indices are given in table 1. The value of lattice parameter is found to be 9.214 Å. The present value of lattice parameter of Chromium ferrite is in good agreement with the reported value.[18-21] The average crystallite size was determined from the measured width of the diffraction using Scherrer formula.[21] The particle size obtained from XRD data is found to be 36 nm.

Table.1: Lattice constant, X-ray density and crystallite size from XRD data

Structural parameters	Values
Lattice constant (a)	9.214 AU
X-Ray density (? x)	5.241 g/cm^3
Crystallite Size (t)	36 nm

Scanning electron micrograph (SEM) of the prepared sample is shown in above Fig. 2. It can be observed that the grains are in nano-meter range. The micrograph reveals dense microstructure with developed grains along with few pores.

Magnetic Properties Study

Fig. 3 shows the magnetization versus field image plot of $CrFe_2O_4$ nanoparticles.

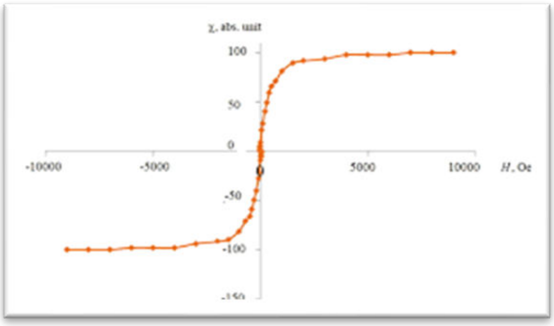

Fig. 3: Hysteresis loop for $CrFe_2O_4$ nanoparticles

Fig.2: SEM image of $CrFe_2O_4$ nanoparticles

These plots are used to evaluate saturation magnetization (Ms), remanence magnetization (Mr) and coercivity (Hc). The values of these magnetic parameters are given in table 4. The saturation magnetization values (Ms) are used to calculate magneton number nB are given in table 4. The observed variation in magneton number was also studied by Neel's theory.[22-26] According to Neel's theory the magneton number is the difference of magnetic moment of B sub lattice and A sub lattice respectively, The calculated value of magneton number is also given in table 2. $n_B = M_B - M_A$

Table 2: Magnetic parameters of $CrFe_2O_4$

Magnetization parameters			Magneton number '? B'(? B)	
Mr (emu/gm)	Ms (emu/gm)	Hc (Oe)	Cal.	Obs.
20.14	45.21	221.35	1.2	0.98

IV. CONCLUSIONS

This investigation into chromium ferrite nanoparticles provides valuable insights into the interdependence of structure and magnetism at the nanoscale. The synthesis via the sol-gel auto-combustion technique yielded phase-pure spinel $CrFe_2O_4$ nanoparticles with controlled crystallite size and uniform morphology. Structural characterization confirmed high crystallinity and nanoscale grain size, while magnetic measurements demonstrated clear ferrimagnetic behavior, characterized by moderate coercivity and reduced saturation magnetization compared to bulk ferrites.

The observed magnetic properties were closely linked to particle size, surface spin disorder, and synthesis-induced defects—highlighting the critical role of nanoscale control in optimizing performance. These findings not only enhance the fundamental understanding of $CrFe_2O_4$ systems but also pave the way for their application in magnetically responsive devices, spintronics, and biomedical tools.

In conclusion, chromium ferrite nanoparticles present a compelling platform for future technological advancements, and continued refinement of synthesis parameters and surface engineering will further unlock their potential across multidisciplinary domains.

REFERENCES

1. Dippong T. Characterization and Applications of Metal Ferrite Nanocomposites. Nanomaterials (Basel). 2021 Dec 30;12(1):107. doi: 10.3390/nano12010107. PMID: 35010057; PMCID: PMC8746313.
2. B. Jeyadevan, K. Tohji and K. Nakatsuka, J. Appl.Phys. 76 (1994) 6325.
3. G. F. Goya, H. R. Rechenbury, J. L. Jiang J. Appl. Phys. 84 (1998) 1101.
4. S. Marup, J. Z. Jiang, F. Bodker, A Harsewell, Euro physlett. 56 (2001) 441.
5. Ch. Venkateshwarlu, D. Ravinder,J. Alloy. Compd. 397 (2005) 5.
6. S. J. Stewart, M. Tueros, G. Gerlhicchiarao, R. B. Scrorzelli, Solid. State. Com. 129 (2004) 347.
7. A. Kasak, D. Makovec, A. Zhidarsic, M. Profinik, J. Eur. Ceram. Soc. 24 (2004) 959.
8. A. K. Giri, K. Pellerin, W. Pongsakswad, M. Sorescu, S. Majetich, IEEE Trans. Magn. 36 (2000) 3029.
9. Masaru Tada, Takashi Kanemaru, Takeshi Hara, Takashi Nakagawa, Hiroshi Handa and Masanori Abe, J.
10. Magn. Magn. Mater. 321 (2009) 1414.
11. J. L. Darmann, D. Fiarani Magnetic properties of fine particles North Holland, Amsterdam, 1992.
12. B. D. Cullity, Moments of X-ray diffraction Adison- Wesley publ. co. Landon (1967).
13. L. Néel (1932). Ann. de Phys., 17, 5-105.
14. Dippong T., Deac I.G., Cadar O., Levei E.A. Effect of silica embedding on the structure, morphology and magnetic behavior of $(Zn_{0.6}Mn_{0.4}Fe_2O_4)_\delta/(SiO_2)_{(100-\delta)}$ nanoparticles. Nanomaterials. 2021;11:23332.
15. Jonssan. P. Hanson M. F., Nordblad P. Phys. Rev. B 2050, 61, 1261.
16. T. Tong, W. Du, Z. Q. Qui, J. C. Walker, J. Appl. Phys. 63 (1988) 4105.
17. S. A. Oliver, H. H. Hamdeh and J. C. Ho, Phys. Rev. B 60 (1999) 3400.
18. S. W. Lee, Y. G. Rylln, K. J. Yang, K. D. Jung, S. Y. An, C. S. Kim, J. Appl. Phys. 91 (2002) 7610.
19. A. Cabonas, H. Poliakaff, J. Mater. Chem. 11 (2001) 1408.
20. M. A. Ahmed, N. Okasha, J. Magn. Magn. Mater. 321 (2009) 3436.
21. S. M. Patange, Sagar E. Shirsath, B. G. Toksha, S. S. Jadhav, S. J. Shukla, K. M. Jadhav, Appl. Phys. A: 95, (2009) 429.
22. P. B. Pandya, H. H. Joshi, R. G. Kulkarni, J. Mater. Sci. Lett. 10 (1991) 474.
23. S. H. Patil, S. I. Patil, S. N. Kadam, B. K. Chougule, Ind. J. Pure Appl. Phys 30 (1992) 183.
24. D. R. Mane, U. N. Devatwal, K. M. Jadhav, Mater. Lett. 44 (2000) 91.
25. Chand P., Vaish S., Kumar P. Structural, optical and dielectric properties of transition metal (MFe_2O_4; M = Co, Ni and Zn) nanoferrites. Phys. B Condens. Matter. 2017;524:53–63.
26. Asghar K., Qasim M., Das D. Preparation and characterization of mesoporous magnetic $MnFe_2O_4$@ $mSiO_2$ nanocomposite for drug delivery application. Mater. Today Proc. 2020;26:87–93.