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Chemical Synthesis, Structural and Superparamagnetic behavior of Zinc Doped Cadmium Nano Ferrite Applications

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ABSTRACT

The composition of Cd Zn_x $Fe_{2-x}O_4$ (x = 0, 0.005, 0.010, 0.015) nano-ferrites that were synthesised with Zn doping Cd doping were examined utilising the Sol-gel method. The single-phase cubic spinel structure was verified by XRD investigation, and SEM Micro grain pictures in the nanometer range are displayed. These images are typical of spinel nano-ferrites. The crystallite's estimated size has been determined to be between 14 and 19 nanometers (nm) in size. While the crystallite size is shown to grow with zinc content, the lattice parameter (a=b=c) decreases. The VSM technique was used to measure magnetization (Vibrating Sample Magnetometer). By substituting zinc, hard ferrite material may be converted to soft ferrite, used in high-density recording media, and microwave devices. The ZFC & FC curves at low temperature (5k) expressed the blocking temperature from 174 to 209 K.

Keywords : Sol-gel Method; XRD; SEM; TEP; Magnetic behavior (5k and 300k).

I. INTRODUCTION

The relevance of material science in study increased as a result of the intriguing uses and characteristics that materials showed in a variety of domains. It covers a wide range of applications in engineering, biology, physics, medicine, and chemistry. The study of materials' structures and characteristics is where material science got its start. Characterization of materials whose characteristics and performance are linked to their microstructure is the major focus of material science. Applications for magnetic nanoparticles include data storage, MRI, magnetic fluids, biotechnology, and others [1-3]. Due to its control on the size distribution, topography, form, and density of the particles—factors heavily influencing the behaviours of these materials—the preparation process is particularly crucial. The most popular superparamagnetic nanoparticles for usage in a variety of biomedical applications are iron oxide nanoparticles, which have distinctive qualities such ultrafine diameters and a high surface area to mass ratio [4]. Soft ferrite with high magnetic permeability and minimal loss is called Mn nano spinel ferrite. Magnetic recording medium, transformer coils, microwave equipment, computer memory chips, and other items are examples of many uses. Over the past few years, magnetic nano-ferrite particles have attracted a lot of attention. High-density magnetic recording frequently makes use of these particles [5]. Low cost, high curie temperature, high saturation magnetization, and hysteresis loop qualities making them ideal for absorbents, high-density recording media, and microwave devices [6].

Due to atoms occupying a significant portion of the grain boundary region, they display unique features compared to bulk, including dislocation, spin canting, superparamagnetic (sp), and surface anisotropy, among others. This characteristic enables these materials to be adaptably customised for certain purposes [7]. Ferrites are often employed in a variety of magnetic components, including magnetic heads, inductors, and transformers in high-frequency resonance circuits [8]. The distribution of cations among tetrahedral (A) and octahedral (B) sites gives rise to the intriguing physical and chemical characteristics of nano ferrites [9]. Additionally, they are utilised in MRI, Target medication delivery, cancer therapy using hyperthermia [10–13], high-density storage systems, and magnetic fluids [14–15].

The impact of cobalt doping on nickel ferrite nanocrystals was investigated by Simi Debnath et al. [16]. Cd on the structural, magnetic and electrical properties of nanostructured Mn–Zn ferrite [17]. Synthesis, electrical, and magnetic properties of Ni0.5-xCdxZn0.5Fe2O4 (with X = 0.0, 0.15, 0.30, and 0.45) ceramics by simple solid-state method [18]. Sol-gel, co-precipitation, micro-emulsion, hydrothermal, reverse micelle, ceramic, solid-state reaction, combustion, and spark plasma sintering were all used to create nanosized spinel ferrites. The current study discusses the synthesis, structural and magnetic characteristics of Zn-Cd ferrites using Sol-gel method.

II. Materials and Methods

Using zinc, cadmium, ferric nitrates, citric acid, and 99% pure ammonia as source ingredients, ferrite particles with the chemical formula Cd Zn_x $Fe_{2-x}O_4$ (x = 0, 0.005, 0.010, 0.015) were created using the sol-gel method at low temperature. Distilled water was used to dissolve the necessary amount of metal nitrate and citric acid, which was then agitated to create a clear, uniform solution and heated to 80 °C. Ammonia was afterwards added to bring the pH level to 7. This liquid was evaporated at a temperature of about 180 °C, producing a burnt powder that was then pulverised in an agate mortar, calcined for four hours at 500 °C, and cooled to room temperature. Prepared samples for structural characterisation were analysed using an X-ray diffractometer (Philips) and Cu K radiation (=1.5405), with a step size of 4°/min, in the Bragg's range of 10° to 80°.

III. Results and Discussion

3.1 XRD

Crystalline powders were effectively characterised using XRD as a technique. Through XRD investigation of Cd Zn_x $Fe_{2-x}O_4$ (x = 0, 0.005, 0.010, 0.015) samples, phase formation and the microstructural research were verified. Fig. 1 shows the XRD patterns, which are denoted by the numbers (111), (220), (311), (222), (422), and (511). (440). It demonstrated the single-phase cubic spinel structure of ferrites devoid of any impurity pickup. Samples that have been developed have crystallite sizes between 14 and 19 nm. Unit cell expansion is confirmed by a decrease in lattice constant value with zinc doped [15].

The substitution of the Zn^{2+} ion's (0.83) tiny ionic radius with the Cd^{2+}(0.97) ion's slightly larger ionic radius results in a minor decrease in lattice constant with an increase in Cd^{2+} concentration. The findings and the reports in the literature are in good accord [19]. the volume of the unit cell is changing with the doping concentration of Zn. The produced samples' X-ray densities are directly inversely correlated with their molecular weights. When Zn^{2+} ions are doped in place of lighter Fe^{+3} ions, the result of this is seen as an increase in the molecular weight of the sample as shown in the fluctuation in X-ray density with Zn^{2+} ion concentration [20-23].

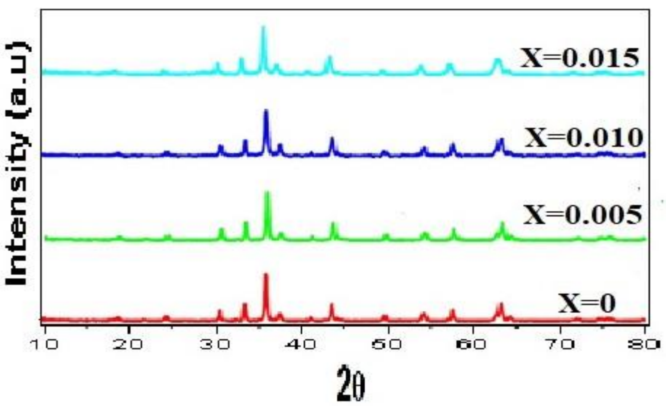


Fig. 1. X-ray diffraction patterns of Zn doped Cd nano ferrites

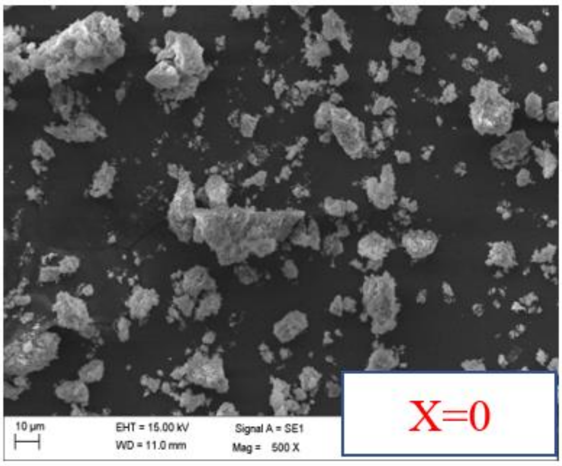
As zinc ion doping in cadmium ferrite grows, X-ray density also rises. It is implied that the mass of the doped ions used in place of the Fe^{3+} ions determine how the X-ray density changes [24]. Table 1. lists the volume of the unit cell, x-ray density, crystallite size, and lattice characteristics for various $CdZn_xFe_{2-x}O_4$ (x = 0, 0.005, 0.010, 0.015).

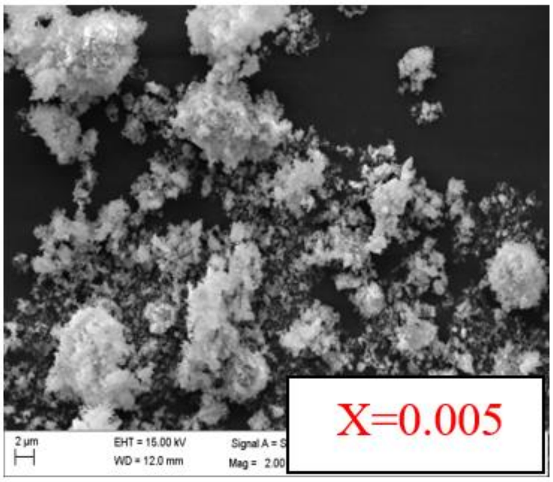
Table 1. Structural parameters of Zn doped Cd nano ferrites

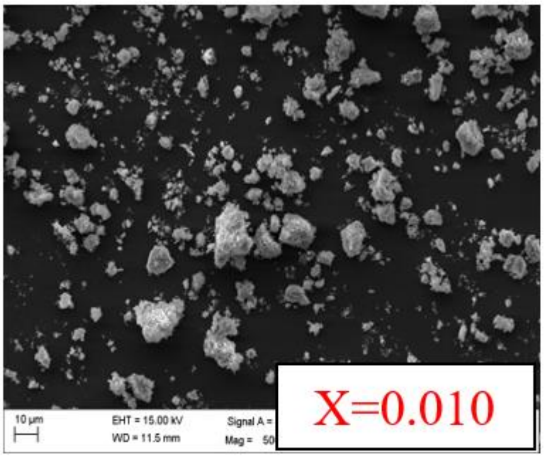
$CdZn_xFe_{2-x}O_4$	Cry.size (nm)	Lattice constant (A°)	X-ray density (gm/cc)	Vol. of the unit cell (A°)
X=0.0	14.23	8.42	4.40	600.00
X=0.005	15.04	8.43	4.43	608.02
X=0.010	12.87	8.38	4.49	599.10
X=0.015	19.00	8.35	4.56	590.04

3.2 SEM

Scanning electron microscopy was used to analyse the morphology of the samples created using both procedures. microscopy (SEM). Information regarding the kind and size of grains is provided by the microstructural analysis. Growth in the samples, which has an impact on the material's physical and electrical characteristics. In SEM Figures are displayed in Fig. 2. The micrographs clearly show that the produced materials are nanosized. and particle aggregation provides prepared samples their magnetic properties [25-27]. The results are smaller, more homogeneous, and more uniform.







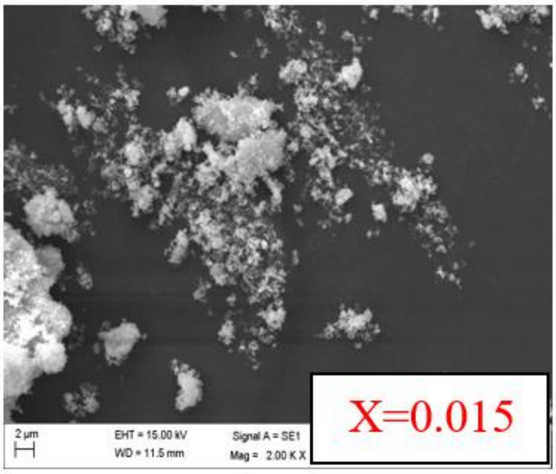


Fig. 2. SEM Micrographs of Zn doped Cd nano ferrites

3.3 Magnetic properties (5k and 300k)

Vibration Sample Magnetometer was used to measure the magnetization at room temperature (VSM). To do this, produced micro ferrite samples were formed into pellets and calcined at 500 °C for four hours at a rate of 4 °C/min. Fig. 3 Hysteresis Loops for Zn Doped Cd Ferrites showed that the magnetization (M) was dependent on the applied magnetic field (H). Utilizing hysteresis loops, different magnetic characteristics including saturation magnetization MS, remanence magnetization Mr, and coercivity HC were measured and summarised. According to the hysteresis loop (Fig. 3), the soft ferrite had the greatest Zn doped ferrite (x = 0.015) and the hard ferrite was pure Cd ferrite with a high squareness ratio [28-30]. Due to this, the system switches from hard to soft ferrite when Zn is substituted for Cd. According to reports, the size and form of the M-H loop are influenced by a number of different elements, including as the method of manufacturing, the materials used, the temperature and duration of the sintering process, as well as the grain size [31–34].

According to the computed results, the saturation and remanent magnetization values in Mg nano ferrites decrease with an increase in the Zn doping concentration, as shown in Table 2. The Cd Znx Fe2-xO4 (x = 0, 0.005, 0.010, 0.015) sample's saturation magnetization (Ms = 38.51 emu/gm) result indicated that the samples have uses in microwave and recording devices [35-38]. The doping of ions from Zn materials affects coercivity [39-44]. Coercivity values vary from 86 to 98 Oe. The squareness ratio of the produced Zn doped Cd nanoferrites fell as the replacement concentration increased. When a result of these findings, it can be deduced that the magnetic properties of the samples change from being hard magnetic to being soft magnetic as the Zn content in the manufactured Cd micro ferrites increases [45]. These magnetic materials may be utilised to create soft magnets, which can then be employed in the cores of transformers, motors, electromagnets [46-50], etc.

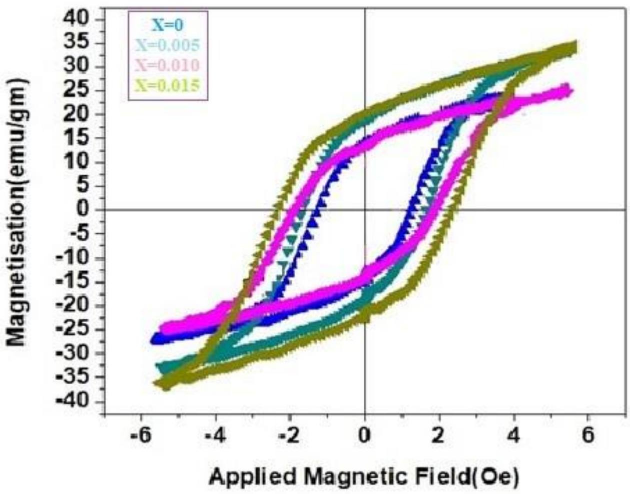


Fig. 3. M-H loop for Zn doped Cd nano ferrites

The low temperature (5k) magnetization behaviour for Zn Doped Cd nano ferrites is shown in Fig.4 when the parameter "T" is varied. As a result, the area T> TB revealed the superparamagnetic nature [51]. The ZFC & FC curves both expressed the TB 174 to 209 K. These materials used in all type of medical and electronic applications [52-54].

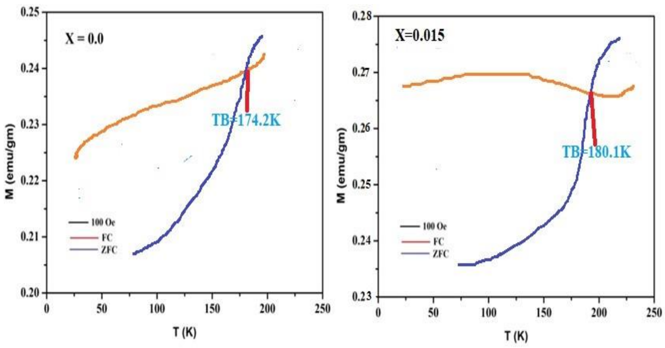


Fig. 4. M-T loops (x=0.0 and 0.015) for Zn doped Cd nano ferrites

Table 2. Various magnetic parameters of Zn doped Cd nano ferrites

$Cd\,Zn_x\,Fe_{2-x}O_4$	M.W	M_S (emu/gm)	H_C (Oe)	M_R (emu/gm)	$S = M_R/M_S$	TB(K)
X=0.0	201.81	34.13	86.45	5.21	0.15	174.2
X=0.005	204.46	37.24	77.80	4.11	0.11	176.9
X=0.010	210.22	37.11	89.99	7.21	0.19	179.0
X=0.015	212.96	38.51	97.6	7.29	0.18	180.1

IV. CONCLUSIONS

The sol-gel process was used to create a series of Zn doped Cd nano ferrites with x = 0.0, 0.005, 0.010, and 0.015. All of the mixtures formed a single-phase spinel structure devoid of any impurities, according to XRD examination. The lattice parameter and average crystallite size of Cd ferrite have risen due to the substitution of Zn. With an increase in Zn content, the saturation magnetization dropped. This demonstrates that the replacement of Zn for the hard ferrite material resulted in the soft ferrite. The fluctuation in the coercivity of nanoparticles in the multidomain area is used to explain how coercivity changes with Zn concentration. ZFC and FC curves were then used to study the low temperature magnetic characteristics. To further support the fact that the nanoparticle is superparamagnetic, the M-H loops were traced. In the making of soft magnets, several sorts of materials may thus be expected to be used.

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Conflicts of Interest
The authors declare no conflict of interest.

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