Influence of Gamma Irradiation on the Structural Properties of Cobalt Ferrite Nanoparticles

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Abstract: In this work, we report influence of gamma irradiation on the structural properties of cobalt ferrite nanoparticles ($CoFeO_4$). Cobalt ferrite nanoparticles were prepared by a standard Sol-Gel auto-combustion technique. AR grade nitrates of constituent ions of Co and Fe were used for the preparation and citric acid was used as a fuel. Metal nitrates to fuel ratio was taken as decided according to propellant chemistry i.e. 1:3. The as prepared powder was sintered at 500˚C for 4hr to obtain good crystallinity and is used for further characterization. X-ray diffraction technique was used to know single phase cubic spinel structure of the synthesized samples before and after irradiation. The X-ray analysis confirmed the single phase cubic spinel structure and also the nanocrystalline nature of the prepared sample before and after the irradiation. Particle size determined using XRD data is of the order of 31 nm which is reduced after gamma irradiation to 21 nm.

Index Terms - Cobalt Ferrite, Sol-gel auto combustion, Gamma irradiation, XRD.

I. INTRODUCTION

Ferrites with metal oxide (MO) and iron oxide (Fe_2O_3) are the important class of magnetic materials which have many applications based on their excellent electrical and magnetic properties [1]. These materials can be easily prepared in bulk as well as in nano size form by using various techniques. On the basis of crystal structure, ferrite can be classified into three main types; spinel, garnet and Hexagonal. Spinel ferrite with general formula MFe_2O_4 (where, M stands for divalent metal ions like Co, Ni, Zn, Cd etc.) finds an important place in today's market as they exists very interesting electrical (d. c. resistivity, dielectric etc.) and magnetic (Saturation magnetization, coercivity, Mobility, etc) properties [1, 2]. Spinel ferrite posses two interstitial sites namely tetrahedral (A) and octahedral [B] in which cations of different size and nature can be incorporated thereby changing the properties [3, 4]. The electrical and magnetic properties can be modified as per the need or application, by using suitable method of preparation as well as by adding different cations. It is also reported in literature that, the properties of spinel ferrites can also be altered by various radiations like gamma, laser and swift heavy ions. These radiations may produce defects or distortion in crystal structure which changes structural, electrical and magnetic properties of spinel ferrite nanoparticles.

In the present work, cobalt ferrite nanoparticles were synthesized using sol-gel auto combustion technique and their structural properties were investigated before and after gamma irradiation. The results of crystallite size, lattice constant, X-ray density etc. structural parameter obtained before and after gamma irradiation are presented in this work..

II. EXPERIMENTAL METHOD

Preparation

The nanocrystalline sample of cobalt ferrite ($CoFe_2O_4$) was prepared using sol-gel auto combustion method. AR grade chemicals such as cobalt nitrate ($Co(NO_3)_2$), ferric nitrate ($Fe(NO_3)_3$) and citric acid ($C_6H_8O_7$) were used for the synthesis. The metal nitrates to fuel (citric acid) ratio was taken as 1:3. Ammonia solution was added to maintain the pH 7. The temperature required for the synthesis of cobalt ferrite nanoparticles was low that is around 110 ˚C. The as-synthesized powder is annealed at 650°C for 4 h and then used for further characterizations. The detailed procedure of synthesis method is reported in earlier literature [5].

Characterizations

The prepared samples were characterized by X-ray diffraction (XRD) technique, which was employed to characterize the prepared nanoparticles using REGAKU X-ray diffractometer. The XRD patterns were recorded at room temperature in the 2θ range of 20˚ to 80˚ using Cu-Kα radiation (λ = 1.54056 Å) [6].

III. RESULTS AND DISCUSSION

X-Ray diffraction studies

The X-ray diffraction patterns of the $CoFe_2O_4$ spinel ferrite nanoparticles before and after gamma irradiation are shown in fig.1. The entire XRD patterns show the reflections belonging to cubic spinel structure for pristine and irradiated samples; no extra peaks have been observed in the XRD patterns. The single phase formations of compounds under investigations were confirmed from the analysis of XRD pattern. The intensity of (311) plane is more as compared to other planes like (220), (222), (400), (422), (511) and (440) and is chosen for the determination of crystallite size. It is also observed from fig. 1 that, the reflections after gamma irradiation are slightly broader as compared to the sample before irradiation. Using XRD data, various structural parameters were determined before and gamma irradiation.

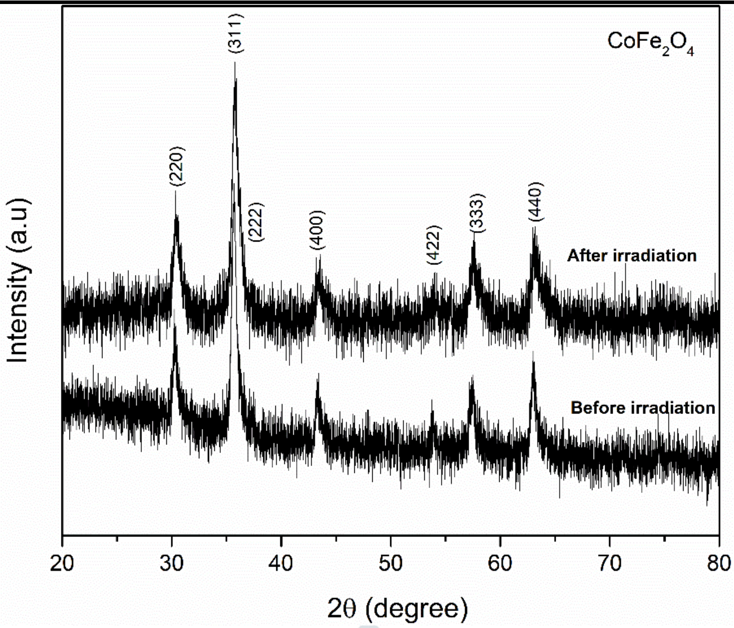

Fig. 1: X-ray diffraction patterns of $CoFe_2O_4$ nanoparticles before and after gamma irradiation

Lattice constant (a)

The lattice constant (a) was calculated using the standard relation. $a = d\sqrt{h^2 + k^2 + l^2}$), where symbols have their usual meanings. The obtained values of the lattice constant 'a' are given in table 1. It is found that the lattice constant decreases after irradiation. The decrease in lattice constant is attributed to the change in the stress of the samples after irradiation [6].

Unit cell volume (V)

The unit cell volume (V) shows gradual decrease after irradiation in the present sample. The decrease in unit cell volume is attributed to decrease in lattice constant of the sample under investigation [7].

X-ray density (d_X)

X-ray density was calculated using the standard relation $d_X = 8M/Na^3$, where symbols have their usual meanings. Similar to lattice constant, it is observed that, the X-ray density also decrease after irradiation. The decrease in X-ray density is attributed to the stress of the samples due to irradiation [8].

Table 1: Lattice parameter (a), X-ray density (d_x) and crystallite size and volume of unit cell (V) of cobalt ferrite nanoparticles before and after irradiation [9]

$CoFe_2O_4$	a (Å)	V (Å^3)	t (nm)	d_x (gm/cm^3)
Before	8.3828	589.1	31	5.3308
After	8.3619	584.7	21	5.3711

Hopping length (L_A and L_B)

The hopping lengths decrease after irradiation. The values of hopping length (L_A and L_B) are given in table 3. Using the experimental values of lattice constant 'a' and oxygen positional parameter 'u' (u = 0.381 Å) [9] other structural parameters such as tetrahedral bond length (d_{AX}), octahedral bond length (d_{BX}), tetra edge (d_{AXE}) and octa edge (d_{BXE}) were calculated for pristine and irradiated samples by using standard relations and the values are tabulated in table 3. It is evident from table 3 that the tetrahedral bond length, octahedral bond length, tetrahedral edge and octahedral edges decrease after irradiation. This is attributed to the decrease in lattice constant after irradiation.

Table 2: Hopping length (L_A, L_B), tetrahedral bond (d_{AL}), octahedral bond (d_{BL}), Tetra edge (d_{AE}) and Octa edge (d_{BEU}) shared and unshared of cobalt ferrite nanoparticles before and after irradiation.

$CoFe_2O_4$	L_A (Å)	L_B (Å)	d_{AL} (Å)	d_{BL} (Å)	d_{AE} (Å)	d_{BEU}	
						Shared	Unshared
Before	3.6299	2.9638	1.9021	2.0466	3.1060	2.8215	2.9655
After	2.5235	2.4440	1.8973	2.0415	3.0983	2.8145	2.9581

Crystallite size (t)

The crystallite size was calculated using Debye-Scherer's formula. The plane (311) with maximum intensity was considered for full width at half maxima (FWHM), the obtained values of crystallite size given in table 1 suggests that the prepared samples have nanocrystalline nature. The crystallite size varies in between 31 nm to 21 nm. The crystal size decreased after irradiation [11].

IV. CONCLUSION

The nanocrystalline $CoFe_2O_4$ nanoparticles were successfully synthesized via sol-gel auto combustion technique using AR grade metal nitrates and citric acid as a fuel. The X-ray diffraction results for unirradiated and irradiated $CoFe_2O_4$ showed the formation of single phase cubic spinel structure. The crystallite size confirms the nanocrystalline nature of the samples. The lattice constant is found to decrease after irradiation. The particle size of the samples calculated using the Debye Scherrer's formula was obtained in the range of 20-31 nm.

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