Structural, Williamson-Hall Plot and Size-strain Analysis of $\text{Mg}_x\text{Ni}_{1-x}\text{Al}_x\text{Fe}_{2-x}\text{O}_4$ Ferrites

Sheela S.Gandhad¹, Preeti M.Patil², S.N.Mathad^{3*}, Leena V.Hublikar⁴,
P.R.Jeergal¹, S.U.Durgadsimi⁵, R.B.Pujar¹

¹ Department of Physics, P.C. Jabin Science College Hubballi-580031, Karnataka, India

² Department of Physics, Government First Grade College, Kalaghatagi, Karnataka, India

³ Department of Physics, K.L.E Institute of Technology-580030, Karnataka, India

⁴ Department of Chemistry, P.C. Jabin Science College Hubballi-580031, Karnataka, India

⁵ Department of Physics, Basaveshwar Engineering College, Bagalkot, Karnataka, 587102 India

ABSTRACT: In the present study Mg-Ni-Al ferrites materials were synthesized by wide-eyed ceramic method (solid-state method). The formation of cubic single phase was affirmed by XRD of Mg-Ni-Al ferrite. The variation of lattice constant (a) with dopant aluminum (Al) is assigned to Vegard's law. The crystallite size(D), lattice constant(a), micro strain(ϵ), X-ray density ($\Delta\rho$), dislocation density (ρ_D), hopping lengths (L_A and L_B), Bond length (A-O and B-O) and Ionic radii (r_A and r_B), also reported. The Williamson-Hall plot and size-strain plot also employed to understand the structural and mechanical attributes of ferrites samples.

KEYWORDS: Size-strain Analysis, materials, XRD, EDAX analysis,

<https://doi.org/10.29294/IJASE.5.4.2019.1146-1153>

© 2019 Mahendrapublications.com, All rights reserved

1. INTRODUCTION

Magnetic nanoparticles (MNPs) have been intensively studied for the reason that, they possess antithetic physical properties from macro and bulk counterparts [1-3]. Unique properties have high potential in tons of applications such as biomedicine, anti-bacteria, drug delivery, data storage and environmental treatment [1-7]. Design of new materials to manufacture magnetic, electric, electronic, microwave and biomedical devices have encouraged scientific and technological community to investigate structural and chemical properties of multi-component inorganic nanostructures. Various synthesis techniques are being used to alter physical and chemical properties of materials to obtain desired material characteristics suited to particular applications [8]. They include high capacity batteries, electrochromic displays, and waste-water cleaning, low magnetization ferro-fluids, intercalation electrodes in rechargeable batteries and as strong oxidizing agents [9-10]. Ferrites have immense practical applications from microwave to radio frequencies on account of the fact that Ac fields do not induce undesirable eddy currents in insulating materials [11-12]. Novel electrical and magnetic behaviors are observed for the nano sized magnetic particles when compared to that of the bulk counterparts [11]. These ferrites can be synthesized through various methods namely ceramic method [13-14], sol-gel Method [15] microwave method [16], combustion method [17], hydrothermal method [18],

oxalate co-precipitation technique [19]. The optical, electrical, magnetic and antibacterial activities of NiFe_2O_4 and MgFe_2O_4 reported by P. A. Udhaya *et.al* [20]. Nickel and Magnesium ferrite is extensively used in a number of electronic devices due to their high permeability at high frequency, remarkable high electrical resistivity, mechanical hardness, chemical stability and reasonable cost [21]. Detailed zinc doped zinc in nickel-copper ferrites and its dielectric properties reported [22]. Magnesium ferrite is a soft magnetic n-type semiconducting material, which finds a number of practical applications in heterogeneous catalysis, adsorption, sensors, and in magnetic technologies [23]. Citrate Gel auto combustion technique is a convenient way for obtaining a homogeneous nano sized mixed Ni-Mg ferrites and magnetic properties were studied [24-25]. Aluminum doped different metal ferrites structural and photocatalytic activity reported [26].

In this study, high purity $\text{Mg}_x\text{Ni}_{1-x}\text{Al}_x\text{Fe}_{2-x}\text{O}_4$ ferrites have been easily prepared via the low-cost solid state method. Prepared ceramics were investigated the effect of magnesium doping in nickel and aluminum doping in iron on the structural, morphological, and mechanical properties elaborately reported. The W-H plot and size strain plots were studied, in a widespread way and the results have been compared.

2. EXPERIMENTAL METHOD

High purity Nickel oxide (NiO), cadmium oxide (CdO), aluminum oxide (Al_2O_3) and ferric oxide (Fe_2O_3)

*Corresponding Author: physicssiddu@gmail.com

Received: 11.04.2019

Accepted: 18.05.2019

Published on: 27.05.2019

Sheela S. Gandhad et al.,

were combined in thoroughly molar proportions in an agate mortar to synthesis $Mg_xNi_{1-x}Al_xFe_{2-x}O_4$ ferrites which are subjected to hard milling (4 hour in agate mortar) for uniform homogenization in acetone medium. Pellets were prepared by applying a pressure about five tons for five minutes which are presented at

800°C for 10hrs and furnace cooled. The schematic flow of the work is shown in Fig.1. Solid-state reaction route is employed preparation ferrites by heating higher temperatures, 1100 °C for 15hrs in order to complete the reaction.

Figure 1 Schematic representation of ferrite work

3. RESULT AND DISCUSSION

3.1 Structural studies

The XRD patterns of $Mg_xNi_{1-x}Al_xFe_{2-x}O_4$ ferrites without impurity peaks were noticed and shown in Fig.2. Diffraction peaks corresponding to (2 2 0), (3 1 1), (2 2 2), (4 0 0), (4 2 2), (5 1 1), and (4 4 0) reflections provided clear evidence for cubic spinel structure. The various parameters were calculated using following relations,

The diffraction maxima from Bragg's law is prevailed by [26]

$$2d_{hkl} \cdot \sin \theta = n\lambda \quad \text{.....(1)}$$

$$d = \frac{a}{(h^2 + k^2 + l^2)^{1/2}} \quad \text{..... (2)}$$

Average Crystallite size (D) is calculated by Debye-Scherrer's formula [20]

$$D = \frac{K \cdot \lambda}{\beta_D \cdot \cos \theta} \quad \text{-----(3)}$$

Where, D is size of the particle, λ is the wavelength of x-rays (1.5406 Å), θ is Bragg angle for the peak and pure diffraction broadening β . The value of K is taken 0.9 in present case.

It is observed that as the concentration of Al^{3+} ions increases, the lattice parameter (a) found decreasing trend. The variation of lattice constant with aluminum content is shown in Fig.3. Experimental lattice parameter decreases systematically with increasing

aluminum (x) values providing abundant nourishment Vegard's law. Experimental lattice parameter observed in the range 8.3925-8.4696Å⁰ decreases with increasing Al^{3+} ions concentration in the given spinel oxides. The Ni^{2+} ions have smaller ionic radii (0.69Å⁰), than Mg^{2+} ions (0.72Å⁰) in the octahedral sites, a partial replacement of the Mg^{2+} ions by the Ni^{2+} ions causes shrinkage of unit cell dimensions, thereby diminishing the lattice parameter and also due to Al^{3+} doping can be explained on the basis of difference in their ionic radius of Fe and Al ions. (Ionic radius of Al^{3+} ion is 0.57 Å and Fe^{3+} ion 0.67 Å) [27]. Thus it is interpreted on the basis of the relative ionic radii of Ni^{2+} , Mg^{2+} , Al^{3+} and Fe^{3+} ions present in the ferrite system. The second order polynomial fit for the process of being varied of lattice parameter (a) with aluminum composition (x) is given by

$$a = 0.4125x^2 - 0.4571x + 8.5103 \quad \text{-----(4)}$$

The distance between magnetic ions (hopping length) in A site (Tetrahedral) and B site (Octahedral) were calculated by using [14,17] the complying relations $\{(L_A \text{ and } L_B)\}$

$$L_A = \frac{a \times \sqrt{3}}{4} \quad \text{----- (5)}$$

$$L_B = \frac{a \times \sqrt{2}}{4} \quad \text{..... (6)}$$

where a is lattice constant. The ion jump lengths (L_A and L_B) are directly varies to lattice parameter (a).

Thus, it was detected that the ions jump lengths decreases with the increase in the aluminum (Al) concentration.

The lattice constant ($a=b=c$), cell volume (V), Dislocation density (ρ_D), Hopping lengths (tetrahedral

site (L_A) and octahedral site (L_B)) were systematically order in Table No. 1.

Figure 2 XRD pattern of $Mg_xNi_{1-x}Al_xFe_{2-x}O_4$ ($x=0.1, 0.2, 0.3$ and 0.4) ferrite synthesized by Solid State reaction method

Figure 3 Variation of lattice parameter with composition (X)

Figure 4. EDAX analysis of $Mg_xNi_{1-x}Al_xFe_{2-x}O_4$ ferrites

Fig.5. EDAX analysis of $Mg_xNi_{1-x}Al_xFe_{2-x}O_4$ ferrites

Figure 6 SEM images (EDAX analysis) with corresponding elemental mapping of Ferrites (X=0.1)

3.2 Williamson-Hall analysis and “Size-Strain plot”(SSP) analysis

The distinct approaches presented in W-H analysis, we assume that size and strain broadening are additive components of the total integral breadth of a Bragg peak [28-30]. The distinct angle (θ) dependencies of both effects laid the basis for the separation of size and strain broadening in the analysis of Williamson and Hall [30-31].

$$\beta_{hkl} \cos \theta = \frac{K \cdot \lambda}{D} + 4\epsilon \sin \theta \quad \dots\dots\dots(13)$$

Fig.7 shows the variation between the $\beta \cos \theta$ vs. $\sin \theta$ (W-H analysis). The equation (13) represents (linear form) $y = mx + c$ where $m = \text{strain}$ and $c = 1/D$, so that the linear plot of $\beta \cos \theta$ vs. $\sin \theta$ gives the slope as lattice strain (ϵ) and the intercept as $1/D$. The “size-

strain plot” (SSP) is a instrument to interpret the quantity of isotropic nature and micro-strain contribution. The evaluation of the size-strain parameters can be obtained by considering an average (SSP), which has the advantage that less weight is given to data from reflections at high angles, where the precision is usually lower which is shown in Fig. 8. In this approximation, we assume that the “crystallite size” profile is described by a Lorentzian function and the “strain profile” by a Gaussian function [29-32]. Accordingly, we have:

$$(d_{hkl} \beta_{hkl} \cos \theta)^2 = \frac{K \cdot \lambda}{D} (d_{hkl}^2 \beta_{hkl} \cos \theta) + \left(\frac{\epsilon}{2} \right)^2 \quad \dots\dots\dots(14)$$

Where $K=3/4$, a constant which depends on the shape of the ferrite samples.

In Fig. 8, similarly to the W-H methods, the term $(d_{hkl} \beta_{hkl} \cos \theta)^2$ is plotted with respect to $(d_{hkl}^2 \beta_{hkl} \cos \theta)$

for the all orientation peaks of Mg- Ni-Al ferrite samples with the cubic spinel structure. The detailed crystallite size and strain calculated from W-H plot and SSP has been reported in Table 4. Results of lattice

strain and average crystallite size of samples encountered in good agreement with the value obtained from the equations (Tabulated in Table.4).

Figure 7 W-H graph of $\beta \cos \theta$ vs $\sin \theta$ for $\text{Mg}_x\text{Ni}_{1-x}\text{Al}_x\text{Fe}_{2-x}\text{O}_4$ ferrites

Figure 8 Size strain plot of $(d\beta \cos \theta)^2$ vs $d^2 \beta \cos \theta$ for $\text{Mg}_x\text{Ni}_{1-x}\text{Al}_x\text{Fe}_{2-x}\text{O}_4$ ferrites

Table 1 Variation of lattice constant, Volume, Hopping lengths, Bond lengths and Ionic radii of ferrite

x	Lattice parameter a (Å)	Volume of unit cell V (e-30)	Hopping length LA (Å)	Hopping length LB (Å)	Bond Length A-O (Å)	Bond length A-B (Å)	Ionic Radii rA (Å)	Ionic Radii rB (Å)
0.1	8.4696	607.56	3.6674	2.9945	1.8337	2.1174	0.4837	0.7674
0.2	8.4326	599.63	3.6514	2.9814	1.8257	2.1082	0.4757	0.7582
0.3	8.413	595.46	3.6429	2.9744	1.8215	2.1033	0.4715	0.7533
0.4	8.3925	591.12	3.6341	2.9672	1.8170	2.0981	0.4670	0.7481

Table No.2 Variation of Crystallite size, Dislocation density and micro strain of ferrite sample

X=0.1					X=0.2					X=0.3					X=0.4				
Angle 2 θ	D (Å)	Dislocation Density $\rho_D \times 10^{14}$	Micro Strain $\epsilon \times 10^{-4}$	Angle 2 θ	D (Å)	Dislocation Density $\rho_D \times 10^{14}$	Micro Strain $\epsilon \times 10^{-4}$	Angle 2 θ	D (Å)	Dislocation Density $\rho_D \times 10^{14}$	Micro Strain $\epsilon \times 10^{-4}$	Angle 2 θ	D (Å)	Dislocation Density $\rho_D \times 10^{14}$	Micro Strain $\epsilon \times 10^{-4}$	Angle 2 θ	D (Å)	Dislocation Density $\rho_D \times 10^{14}$	Micro Strain $\epsilon \times 10^{-4}$
29.968	378	6.98	9.16	29.950	441	5.1	7.8	30.202	221	20.3	15.6	30.012	301	11.4	11.5				
35.371	410	5.94	8.45	35.353	446	5.0	7.7	35.606	277	12.9	12.5	35.436	355	7.93	9.77				
36.920	335	8.88	1.03	36.917	356	7.8	9.7	37.17	252	15.6	13.7	36.985	305	10.78	1.14				
42.984	303	1.08	1.14	42.94	333	8.9	10.4	43.211	269	13.7	12.7	43.035	309	10.49	11.3				
57.046	408	5.99	8.49	53.528	338	8.7	10.3	57.298	308	10.4	11.2	57.126	317	9.96	10.9				
62.681	395	6.39	8.76	57.049	459	4.7	7.5	62.881	233	18.4	14.9	62.767	257	15.1	13.5				
				62.705	344	8.4	10.1					74.460	79	161.2	44.1				
				65.120	441	5.1	7.8												
				74.25	446	5.0	7.7												
371	7.52	6.17	400		400	6.52	9.07		260	15.2	13.4		275	32.4	16.1				

Table.No.3 EDAX analysis of Ferrite samples

Element	0.1		0.2		0.3		0.4	
	Weight%	Atomic%	Weight%	Atomic%	Weight%	Atomic%	Weight%	Atomic%
O K	31.41	61.18	26.23	55.18	27.58	56.64	28.46	57.58
Mg K	1.62	2.08	1.39	1.92	1.20	1.62	1.78	2.37
Al K	0.19	0.22	0.23	0.29	1.12	1.36	0.95	1.14
Fe K	39.42	22.00	42.80	25.79	40.05	23.56	34.90	20.22
Ni K	27.35	14.52	29.35	16.82	30.05	16.82	33.91	18.69
Totals	100.00		100.00		100.00		100	

Table No.4 Comparison of crystallite size and micro-strain by SSP and W-H analysis

	0.1			0.2			0.3			0.4		
	equation	W-H graph	SSP method	equation	W-H graph	SSP method	equation	W-H graph	SSP method	equation	W-H graph	SSP method
Crystallite Size D (Å)	371	154	99.5	400	128	96.06	260	168	174	275	113	151
Micro strain (ϵ) $\times 10^{-4}$	6.17	3.27	18.7	9.07	2.99	6.48	13.4	1.68	9.53	16.1	1.86	7.52

The quantity of dislocations per unit volume of a material is uttered as dislocation density (ρ_d). These dislocations are 1D crystal defects which are constructed by the boundary between the slipped and unslipped regions. The measure of defects is resolved by evaluating dislocation density. As aluminum content (x) is varied the average size (D), micro-strain(ϵ) and dislocation density also varied which are tabulated Table.No.2.

$$\text{micro-strain}(\epsilon) = \frac{\beta \cos \theta}{4} \quad \dots\dots\dots (7)$$

$$\text{Dislocation-Density}(\rho_D) = \frac{1}{D^2} \quad \dots\dots\dots (8)$$

The bond lengths (A-O and B-O) and ionic radii (r_A and r_B) on A-site and B-site are calculated using the equation. The calculated values of bond lengths and ionic radii on A-site and B-site are presented in Table 2.

$$A-O = (u - 1/4)a\sqrt{3} \quad \dots\dots\dots (9)$$

$$B-O = (5/8 - u)a \quad \dots\dots\dots (10)$$

$$r_A = (u - 1/4)a\sqrt{3} - r(O^{2-}) \quad \dots\dots\dots (11)$$

$$r_B = (5/8 - u)a - r(O^{2-}) \quad \dots\dots\dots (12)$$

EDAX analysis of the investigated ferrites affirmed the stoichiometric ratio of a $\text{Mg}_x\text{Ni}_{1-x}\text{Al}_x\text{Fe}_{2-x}\text{O}_4$ system as shown in Fig. 4 and Fig.5. The chemical compositions of the investigated Mg-Ni-Al- ferrites were measured to supports the stoichiometric ratio of a given system using energy dispersive X-ray analyses (EDAX). The atomic percentage (at.%) and weight percentage (wt.%) of constituent elements (Ni, Mg, Al Fe and O) are computed theoretically from the intermediate chemical composition ferrites is Tabulated in Table. 3. The elemental analysis as predominated from EDAX is in agreements with the starting materials used for the synthesis like elements Ni, Mg, Al, Fe and O were observed on the EDAX image. SEM images (EDAX-analysis) with corresponding elemental mapping for X=0.1 is shown in Fig. 6. Thus EDX technique provides the effective atomic concentration of distinct components in the top surface layers (ferrites).

4. CONCLUSION

Solid state technique is a favorable room in obtaining homogeneous $\text{Mg}_x\text{Ni}_{1-x}\text{Al}_x\text{Fe}_{2-x}\text{O}_4$ ferrites. X-ray diffraction pattern declares the formation of cubic spinel in single phase without impurity peak with

lattice parameter 8.3925-8.4696Å. The lattice parameter is degree of decrease with the increase of aluminum (Al) substitution in ferrites which indicates that the mixed ferrite system obeys Vegard's law. EDAX patterns confirm the compositional formation of the synthesized samples. The Williamson-Hall plot and size-strain plot also accompaniment realizes the physical attributes of ferrites samples.

REFERENCES

- [1]. Aktas, B., Tagirov, L. Mikailov (Eds.), F., 2013. Nanostructured Magnetic Materials and their Applications, Springer science & business media 143,
- [2]. Tran, N., Webster, T.J.,2010. Magnetic nanoparticles: biomedical applications and challenges,J. Mater. Chem. 20 ,8760-8767.
- [3]. Arruebo, M., Fernandez-Pacheco, R., Ibarra, M.R., Santamaria, J., Magnetic nano-particles for drug delivery,2007. Nano Today 2 (3), 22-32.
- [4]. Reiss, G., Hutten, A.,2005. Magnetic nano-particles: applications beyond data storage, Nat. Mater. 4, 725-726.
- [5]. Kaewmanee, T., Wannapop, S., Phuruangrat, A., Orawan, T. T., Promnopas, W., Sansongsiri, S., Thongtem,S., 2019. Effect of oleic acid content on manganese-zinc ferrite properties, Inorganic Chemistry Communications, 103,87-92
- [6]. Tang, S.C., Lo, I.M., 2013. Magnetic nanoparticles: essential factors for sustainable environmental applications, Water Res. 47, 2613-2632.
- [7]. Ismail, R.A., Sulaiman, G.M., Abdulrahman, S.A., Marzoog, T.R.,2015., Antibacterial activity of magnetic iron oxide nano-particles synthesized by laser ablation in liquid, Mater. Sci. Eng. C 53, 286-297.
- [8]. Chakradhary, V.K. , Ansari, A. , Akhtar, M. J.,2019., Design, synthesis, and testing of high coercivity cobalt doped nickel ferrite nanoparticles for magnetic applications, Journal of Magnetism and Magnetic Materials,469, 674-680
- [9]. Viret, M., Rubi, D., Colson, D., Lebeugle, D., Forget, A., Bonville, P., Dhalenne, G., Saint-Martin, R., André, G., Ott, F.,2012., β -NaFeO₂, a new room-temperature multi-ferroic material, Mater. Res. Bull. 47, 2294-2298
- [10]. Mujasam Batoo, K., Ansari, M. S., 2012., Low temperature-fired Ni-Cu-Zn ferrite nanoparticles through auto-combustion method for multilayer chip inductor applications, Nanoscale Res. Lett. 7 112.
- [11]. Goldman, A.,1990. Recent Advances in Ferrite Materials Technology, in Modern Ferrite Technology, Van Nostrand Reinhold, New York.
- [12]. Rendale, M.K., Mathad, S.N., Vijaya Puri.,2016., Dielectric and magnetic properties of

- substituted Li-Zn ferrite thick films clouded over a half wavelength microstrip rejection filter. ,International Journal of Self-Propagating High-Temperature Synthesis, 25(2), 86-91
- [13]. Patil, M.R., Rendale, M.K., Mathad, S. N., and Pujar, R.B., 2015. Structural and IR study of $\text{Ni}_{0.5-x}\text{Cd}_x\text{Zn}_{0.5}\text{Fe}_2\text{O}_4$, International Journal of Self-Propagating High Temperature Synthesis, 24(4), 241-245
- [14]. Kulkarni, A. B., Mathad, S.N., 2019., Variation in structural and mechanical properties of Cd-doped Co-Zn ferrites, Materials Science for Energy Technologies 2, 455-462
- [15]. Sharifi, I., Shokrollahi, H., 2012, Nano-structural, magnetic and Mössbauer studies of nanosized $\text{Co}_{1-x}\text{Zn}_x\text{Fe}_2\text{O}_4$ synthesized by co-precipitation, J. Magn. Magn.Mater. 324, 2397-2403
- [16]. Molakeri, A. S., Kalyane, S., Mathad, S.N., 2017. Elastic Properties of nickel ferrite synthesized by combustion and microwave method using FT-IR spectra, International Journal of Advanced Science and Engineering, 3 (4) 422-427
- [17]. Pathan, A. T., Mathad, S. N., and. Shaikh, A. M, Infrared spectral studies of Co^{2+} substituted Li-Ni-Zn nano-structured ferrites. International Journal of Self-Propagating High Temperature Synthesis 23, 112 (2014).
- [18]. Aydin, Cihat; Aydin, Handan; Taskin, Mustafa; Yakuphanoglu, Fahrettin, 2018, A Novel Study: The Effect of Graphene Oxide on the Morphology, Crystal Structure, Optical and Electrical Properties of Lanthanum Ferrite Based Nano Electroceramics Synthesized by Hydrothermal Method, Journal of Nanoscience and Nanotechnology, 19(5) 2547-2555.
- [19]. Shedam, R.M., Gadkari, A. B., Mathad, S. N., Shedam, M. R., 2016. Synthesis and structural investigation of nano-sized cadmium ferrite. Journal of Modern Materials, 2 (1), 7-12
- [20]. Aji Udhaya, P., Bessy, T.C., Meena, M., 2019., Antibacterial activity of nickel and magnesium substituted ferrite nanoparticles synthesized via self-combustion method, Material today proceedings, 8, Part 1, pp 169-175
- [21]. Upadhyay, C. and Verma, H. C., 2004, Cation distribution in nanosized Ni-Zn ferrites, Journal of Applied Physics 95, 5746
- [22]. Khemalapure, S. S., Hosamani, P. L., Mathad, S. N., Pujar, A. S., Hiremath, C. S, Jeeragal, P.R., Pawar, S. S., and Pujar, R.B., 2019, Synthesis, Structural and Dielectric Properties of Ni-Zn-Cu Ferrites, Advanced Science, Engineering and Medicine, 11, 1-8
- [23]. Willey, R.J., Noirclerc, P., Busca, G., Chem. Eng. Commun. 123, 1 (1993).
- [24]. Gaffoor, A. and Ravinder, D., 2014. Characterization of Magnesium Substituted Nickel Nano Ferrites Synthesized By Citrate-Gel Auto Combustion Method, 4(4) April, 60-66
- [25]. Haque, M. M., Haniun K.M., Choudhury, S., Bhuiyan, M. A. and M.A.Hakim, 2013, Synthesis, microstructure and magnetic properties of Ni-Mg ferrites, Journal of Ceramic Processing Research. 14, 82
- [26]. Eman Z. Hegazy, Samia A. Kosa, Islam H. Abd Elmaksod and Jawaher T. Mojamami, 2019. Preparation, Characterization and photo catalytic evaluation of Aluminum doped metal ferrites, Ceramics International, 45(6) 7318-7327.
- [27]. Mathad, S.N., Jadhav, R.N., Phadtare, V., Puri, V., 2014. Structural and Mechanical Properties of Strontium doped Barium Niobate Thick-films. International Journal of Self-Propagating High Temperature Synthesis, 23(3), 26-32.
- [28]. Kumar, V. K., Paramesh, D., Venkat Reddy, P., 2015., Effect of Aluminium Doping on Structural and Magnetic Properties of Ni-Zn Ferrite Nanoparticles, World Journal of Nano Science and Engineering, 5, 68-77
- [29]. Khorsand, A. Zak., Abrishami, M. E., Abd., W.H., Majid, Yousefi, R., Hosseini, S.M., 2011., "X-ray analysis of ZnO nanoparticles by Williamsone Hall and size-strain plot methods, Ceram. Inter. 37, 393-398.
- [30]. Kulkarni, A.B., Mathad, S.N., 2018., Effect of Sintering Temperature on Structural Properties of Cd doped Co-Zn Ferrite, Journal of Nano- and Electronic Physics, 10, 01001(4pp)
- [31]. Shashidhargouda, H. R., and Mathad, S.N., 2018., Synthesis and structural analysis of $\text{Ni}_{0.45}\text{Cu}_{0.55}\text{Mn}_2\text{O}_4$ by Williamson-Hall and size-strain plot methods, Ovidius University Annals of Chemistry, 29, 117-120
- [32]. Kulkarni, A. B., Mathad, S.N., 2018., Synthesis and structural analysis of Co-Zn-Cd ferrite by Williamson-Hall and Size-Strain Plot Methods, International Journal of Self-Propagating High-Temperature Synthesis, 27, 1, 37-43