Magnetic Properties of Zr/Ti Substituted Mn-Zn Ferrites

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Abstract – By substituting Zr/Ti in the matrix of Mn-Zn ferrites, T_c , M_s , μ_i , K , H_c and P_h parameters are studied. The variations are explained on the basis of cation preferential sites and hence with the modified strength of exchange interactions of cations. Due to non-magnetic behaviour of the dopants, magnetic properties are decreased and the H_c values are increased. The hysteresis loss (P_h) values are decreased with the substituent concentration increasing the quality of the material.

I. INTRODUCTION

Core loss is one of the major draw backs to use a ferrite in any device as core material. So it is necessary to reduce core losses of a ferrite material. The increase of operating frequency of Switching Mode Power Supplies (SMPS) reduces the size of SMPS. Recently these are being in use from 25 KHz to several MHz [1]. Mn-Zn ferrites are suitable to use as core material in the frequency range below 1 MHz. Recently efforts have been made to develop low power loss material by introducing a foreign cation in the matrix of a ferrite [2]. Substitution of high valency cation in the matrix of Mn-Zn ferrite is expected to reduce the core losses and also alters the physical properties.

II. SAMPLE PREPARATION

Mn-Zn ferrites with the composition $Zr_{0.37+x/2} Mn_{0.58-x/2} Fe_{2.05-2x} O_4$ were prepared. x by conventional double sintering method. Initial firing was done at 1000°C for 3 hrs. and then grounded using ball mill to obtain fine powder. Final sintering was done at 1200°C for 2 hours in air. X-ray diffractograms of all the materials were confirmed the single phase formation of cubic spinel. The obtained lattice parameter 8.519Å is consistent with the reported [3] value 8.4998Å. Using the Laroia Sinha technique [4] the Curie temperature and with the technique explained by Heck [5], the initial permeability measurements were made. At room temperature hysteresis loops for all the materials were traced on applying field of 2.5 K Gauss at 50 Hz with high field loop tracer which was described earlier researchers [6]. Some of the loops are shown in the Fig.1. Grain size measurements were done using SEM and typical photographs are shown in Fig. 2. The results of Curie temperature (T_c), saturation magnetisation (M_s), initial permeability (μ_i), and grain size are tabulated in table 1 and Anisotropic constant(K), Coercivity (H_c), remanence

ratio (B_r/B_s) and hysteresis losses (P_h) are listed in the table 2.

III. RESULTS AND DISCUSSION

Due to non-magnetic behaviour of dopants, magnetic properties are influenced and the loss factor is reduced. The slight increase of T_c and M_s for 0.1 concentration of Zr doped ferrite can be explained with the modified strength of AA, BB and AB interactions assuming that Zr entering A sites. Consequently A sublattice magnetisation reduces which in turn increases M_s . For further increase of Zr concentration, it occupies both tetrahedral (A) and octahedral (B) sites causing reduction in both M_A and M_B . Hence the M_s continuously decreases upto $x = 0.4$. It is note worthy that the T_c is not influenced significantly by dopant concentration from $x = 0.2$ which can be understood in terms of Curie constants C_A and C_B for A and B sublattices. The changes in M_A and M_B may cause T_c to be unaffected because of the dependence on both ($C_A + C_B$) and ($C_A C_B$) as described by earlier scientists [7]. Recently Pal et al., [8] obtained same values of T_c (385°C) for different concentrations of bismuth substitution in Ni-Zn ferrites. The T_c and M_s for Ti doped ferrites are found to be decrease since Ti^{4+} ions prefer only the octahedral sites [9]. This reduces the B sublattice magnetization resulting decrease of the net magnetisation. The variation trend of μ_i with x seems to have correlation with the observed variation of M_s Vs x . However, for $x = 0.1$ of Zr substituted ferrite μ_i value does not reflect the M_s measurement which can be attributed to the rise of anisotropy constant (K) thus reduces the value of μ_i . From the Table 1 it is observed that the grain size(D_g) value decreases with the dopant concentration. This reflects the decrease of magnetic properties and also the decrease of conductivity. The dopants are induced to form the oxygen rich layers at grain boundaries during sintering. This

Table 1. Variation of magnetic properties with dopant concentrations

Dopant conc.	Tc (°C)		Ms (Gauss)		$\mu_i \times 10^2$		Dg (μm)	
	Zr	Ti	Zr	Ti	Zr	Ti	Zr	Ti
0.0	300	300	350	350	14.0	14.0	4.50	4.50
0.1	335	260	420	230	9.0	8.0	4.10	4.15
0.2	330	245	270	190	8.0	7.0	4.00	4.10
0.3	330	225	230	170	7.5	6.5	3.75	4.15
0.4	330	180	190	90	7.0	6.0	3.74	4.20

Table 2. Variation of anisotropic constants, coercivity, remanence ratio and hysteresis loss with concentrations

Dopant conc.	$K \times 10^3$		Hc (Oe)		Br/Bs (%)		$P_h (\text{mm}^2/\text{g})$	
	Zr	Ti	Zr	Ti	Zr	Ti	Zr	Ti
0.0	7.35	7.35	0.62	0.62	16	16	14	14
0.1	9.70	5.90	0.66	0.85	25	31	15	8
0.2	7.00	4.70	0.90	0.90	33	28	8	6
0.3	6.70	4.30	0.95	0.95	30	35	3	4
0.4	6.70	3.70	1.00	0.96	31	39	3	2

Fig. 1 Hysteresis loops for the system $\text{Mn}_{0.58+x/2}\text{Zn}_{0.37+x/2}\text{M}_x\text{Fe}_{2.05-2x}\text{O}_4$.

increases the grain boundary and thus grain size decreases.

The variation of K with x can be explained on the basis of the single-ion anisotropy model [10] in which Fe^{3+} ions present A and B sites contribute separately to the anisotropy energy. The observed Coercive field (H_c) values are found to be increase with the concentration for both the dopants. Van der Zaag et al., [11] reported that the value of H_c increases with the decrease of grain size and this dependence can be interpreted by assuming grain boundary with unit permeability which also accounts for the influence of the grain size on the μ_i of the same ferrite for smaller grains. In the present studies also materials with smaller grains the H_c values are increased as the μ_i values decreased and this can be accounted for the above phenomena. The ratio B_r/B_s does not show a systematic trend for both the series but the values are higher for higher concentrations of Ti^{4+} and Zr^{4+} . This means dopants are increased the value of residual magnetic induction in the substance when the applied field reduced to zero. This is probably related to the spin movement of the cations. The core losses of a power ferrite is sum of the hysteresis loss (P_h), eddy current loss (P_e) and dielectric loss (P_{de}). Area of a loop directly gives the hysteresis loss (P_h) contribution to the core losses. The observed P_h values are found to be decrease and hence the quality of the material is increased. If the operating frequency of Mn Zn ferrites is lower than the relaxation frequency of the domain wall displacement, the core losses is predominant. The hysteresis loss, $P_h = \oint B dH$ which gives [12] the loop area measured under maximum flux density (B_m) and depends on M_s , K , microstructure and magnetostriction (λ_s). Smaller grains increase resistivity and decrease the permeability with the increasing Coercive force.

IV. CONCLUSIONS

1. Initially Zr enters into A sites resulting increase in T_c and M_s .
2. Ti cation prefers B sites which causes reduction in magnetic properties.
3. Coercive field values are increased with the dopant concentration.
4. Hysteresis loss is reduced with the increase of dopant concentration which improves the quality of the material.

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Fig.2 SEM photographs for the system $Mn_{0.58+x/2}Zn_{0.37+x/2}M_xFe_{2.05-2x}O_4$.