Analysis Of The Influence Of Divalent Substitution On The Structural, Morphological And Magnetic Properties Of Mg-Ferrites

Shuaib Mahmud, Tareq Mohammad Faruqi, Mahmudul Hasan

Abstract: This article illustrated the impact of synthesized micro-structured spinel-type polycrystalline ferrites. The technique of conventional double sintering is used \( \text{MgFe}_2\text{O}_4, \text{MgF}_{0.5}\text{Zn}_{0.5}\text{Fe}_2\text{O}_4, \text{MgF}_{0.33}\text{Cu}_{0.2}\text{Mn}_{0.45}\text{Fe}_2\text{O}_4 \) and \( \text{MgF}_{0.33}\text{Cu}_{0.2}\text{Zn}_{0.45}\text{Mn}_{0.49}\text{Fe}_{1.94}\text{O}_4 \) to investigate their impact on the size of the grain, magnetic properties and the effect of divalent substitutions. Impurity phases aren't detectable in the taken cubic spinel of single phases in the X-ray diffraction patterns. In the sample investigation it was observed that the density was tensed to increase, while the porosity decreased with the replacement of divalent ions. Microstructures show that there is an increase in grain growth as the addition of CuO is attributed to the liquid process due to CuO during sintering. At room temperature, all the samples exhibit a nice homogeneity for the sharp deterioration of \( \mu' \) in \( \mu'' \). Lower coercivity is found in all samples suggesting that the compounds are a type of soft ferrite magnets.

Index Terms: Mg-based ferrites, XRD, SEM Microstructure, Curie Temperature, Magnetic Hysteresis.

1 INTRODUCTION

THE ferrites are ceramic, polycrystalline or homogeneous materials composed of various oxides. The main element of ferrites is iron oxide. Having the closed-packed structure, spinel ferrites consists of oxygen ions followed by the formula \( \text{AB}_2\text{O}_4 \) where A refers for tetrahedral and B octahedral sites. In this noble work, variation within the composition of Mg ferrites is created to analyze the structural and magnetic characteristics. The magnetic and non-magnetic material creates an impression on their chemical, physical and mostly magnetic properties due to their divalent substitution. As a result, different characteristics of spinel ferrites have been investigating rather more interest [1-3]. Mg-based ferrites are an essential magnetic material having the useful properties of soft ferrites, high permeability, large temperature of curie, few losses, high mechanical reliability and environmental resilience[4]. The chemical composition and substitution/addition can make proper magnetic material. Tiny divalent ions can change the properties of spinel ferrites. Generally, powerful magnetic materials such as Fe, Co, Ni, Cr, Mn etc. can change their different properties of magnetic, structural as well as in electrical in case of inclusion or delusion of nonmagnetic materials such as Li, Cu, Zn, Mg, Al etc. So the substitution of divalent ions with Mg is expected to show similar magnetic effects and regenerated structural properties in Mg ferrites. The notable impact can be seen due to some changes in factors like grain size, surface layer, sintering temperature, distributions in octahedral and tetrahedral sites [5-8]. It was well known that for high frequency application having large magnetization [9-10]. Mg-based ferrites can be used in transformer, magnetic core of coils, loudspeakers, small electric motors, gas sensors and humidity sensors due to their growing interest [11-13].

The phase analysis with microstructural study and the observation of magnetic behavior such as curie temperature and magnetization properties are the two separated segmentation of this work.

2 METHODOLOGY OF FERRITE PREPARATION

Being usable in a different magnetic device, ferrites are prepared in either polycrystalline form or single crystal form. Several techniques were used to prepare ferrites. All of them are fallen into two categories: Conventional ceramic methodology, i.e. solid-state reaction method where milling of reactions is followed at elevated temperature by sintering technique and wet method. Sol-gel synthesis, chemical co-precipitation method, organic precursor method, reverse micelles method, co-spray roasting, activated sintering, etc. are examples of the wet method. In our research, a series of polycrystalline samples were prepared mixed of Mg ferrites. To prepare the examinee samples, the standard method of the double sintering ceramic was used. High purity oxide (99.99 percent) weighted precisely in this process. Where \( \text{Fe}_2\text{O}_3, \text{CuO}, \text{MgO}, \text{ZnO}, \text{and MnO} \) were used and this process was done focused on their molecular weight. The estimation of the weight proportion of the oxide conjugated with various samples is based on the following equation:

\[
\text{Weight } \% \text{ of oxide} = \frac{\text{M. wt. of oxide} \times \text{required weight of the sample}}{\text{Sum of Mol. wt. of each oxide in a sample}}
\]

In this preparation process, the stoichiometric proportion was required ceramic mortar and pestle and after that in the planetary ball mill, the ball was milled with different sized stainless steel balls and in ethyl alcohol media. This process had taken six (06) hours respectively to complete and the various sized stainless balls were used in this process. The disc-shaped sample which was made from the dried slurry, pre-sintered for five (05) hours at the 950°C temperature. And the sample was cooled down to room temperature at the same rate as that of heating. After crushing the sample once again to make those samples in uniformed tiny crystallites the wet ball milled in distilled water for six (06) long hours. So as to provide with chemically homogeneous and magnetically better
material this preferred lump material was crushed. Getting a homogeneous sample these oxide mixtures were milled thoroughly for 4-6 hours. Hydraulic press was used to pressurized the dried mixture which was added with Polyvinyl Alcohol to get a pellet and toroid shape respectively. Tiny amount of Saturated solution alcohol was used as a binder which was low in quantity and 1.75 ton-cm2 and 1.2 ton-cm2 pressure was applied on the samples. Muffle furnace was used to sintered the samples for two (02) to three (03) hours at 1050°C-1200°C and to get rid of oxide layer the sintered samples then polished.

2.1 Ferrite preparation in Presintering method
This phase of preparing the sample is incredibly crucial because during this state of sample preparation a ferrite is made from its component oxides. The counter diffusion process is responsible for formatting the ferrites in the solid-state reaction. This means that the diffusion requires two (2) or more species of ions that initially pass across the interface of two contacting particles of different component oxides in a different direction. To form spinel ferrite, the reaction happened between Fe2O3 with metal oxide M0.2O2 during its pre-sintering stage of sample preparation. [14]:

MO + Fe2O3
2M0.3+ 4Fe2O3
Fe2O3 + MgO
2M0.4

MO Ferrite
Fe2O3 + Mn Ferrite
Fe2O3 + 0.5MgO + 0.5ZnO
Mg0.5Zn0.5Fe2O4

Fe2O3 + 0.35MgO + 0.2CuO + 0.45ZnO
Mg0.35Cu0.20Zn0.45Fe2O4

Fe2O3 + Mn Ferrite
Fe1.94O1 + 0.35MgO + 0.2CuO + 0.45ZnO + 0.06MnO
Mg0.35Cu0.20Zn0.45Mn0.06Fe1.94O4

3 EXPERIMENTAL TECHNIQUE
3.1 X-rays study
To study the crystalline phases of the prepared samples X-ray diffractometer was used. In this diffraction technique, Cu-Κα radiation was used as a 40kV & 30mA main beam powder with nickel filter at room temperature. The sample pitch of 0.02° with a data collection rate of 1.0 second, a 2θ scan was imposed in between 20° to 70° scale to achieve possible fundamental peaks of the prepared samples where spinel phase is confirmed for all the taken samples in this XRD analysis.

3.2 Microstructure Determination
A scanning electron microscope ((Hitachi S 3400N, type-II, Japan) was used during this process. From the polished pellet shaped sample, we can get the micrographs. Until the micrographs are drawn, the surface of the samples will be engraved at a temperature of 1000°C below their sintering temperature for 15 minutes.

3.3 Curie Temperature Measurement
Hewlett Packard Analyzer (HP-4192A) with a small oven and a thermometer was used to measure the Curie temperature in this work. Induction method was used to calculate the temperature dependent permeability where the specimen formed the core of the coil.

3.4 Magnetization Measurement
To calculate the field dependence of magnetization the VSM 02,(Hirstlab, England) was employed at room temperature.

4 RESULTS
4.1 XRD study
To optimize the properties of prepared samples for different applications XRD analysis is very convenient. The crystal structure identification with lattice constant determination of MgFe2O4, Mg0.5Zn0.5Fe2O4, Mg0.35Cu0.20Zn0.45Fe2O4, and Mg0.35Cu0.20Zn0.45Mn0.06Fe1.94O4 ferrites, the total process was done by the XRD by using diffraction of X-rays (XRD). The XRD trend at room temperature of MgFe2O4, Mg0.5Zn0.5Fe2O4, Mg0.35Cu0.20Zn0.45Fe2O4, and Mg0.35Cu0.20Zn0.45Mn0.06Fe1.94O4 ferrites were recorded by this diffraction technique where Cu-Κα radiation was used. The sample recorded a cubic spinel structure as shown in the analysis of (hkl) values of each peak (Fig. 2). It’s also noticed that the peaks are all well-defined with a lack of haziness. The peaks exhibit the absence of extra peaks which defines the purity of the sample. The absence of extra peaks indicates the purity of the samples. The peaks (220), (311), (400), (422), (511) and (440) belong to the spinel period and all the peaks found correspond well to those of Mg-Zn, Mg-Cu and Mg-Cu-Zn ferrites [15-18]. The location of the peaks along with their defined miller indices is summarized in Table 1.

<p>| TABLE 1 |
| X-ray peak positions of MgFe2O4, Mg0.5Zn0.5Fe2O4, Mg0.35Cu0.20Zn0.45Fe2O4 and Mg0.35Cu0.20Zn0.45Mn0.06Fe1.94O4 ferrites. |</p>
<table>
<thead>
<tr>
<th>Sample Ferrites</th>
<th>At 2θ (degree)</th>
<th>X-ray peak positions along with Miller indices</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(220) (311) (400) (422) (511) (440)</td>
</tr>
<tr>
<td>MgFe2O4</td>
<td>54.62</td>
<td>70.54 25.08 26.85 30.60 51.91</td>
</tr>
<tr>
<td>Mg0.5Zn0.5Fe2O4</td>
<td>81.21</td>
<td>277.28 40.90 24.89 60.39 72.31</td>
</tr>
<tr>
<td>Mg0.35Cu0.20Zn0.45Fe2O4</td>
<td>81.95</td>
<td>21.77 43.55 16.51 59.94 71.86</td>
</tr>
<tr>
<td>Mg0.35Cu0.20Zn0.45Mn0.06Fe1.94O4</td>
<td>31.02</td>
<td>90.84 18.22 8.85 40.48 39.04</td>
</tr>
</tbody>
</table>

Fig. 1 Flow chart of double sintering ceramic method for ferrite material
POROSITY

The Nelson-Riley [19] extrapolation formula was used to get accurate values of the lattice parameter for individual samples and the data was taken from X-ray data. The Nelson-Riley formula is defined as,

\[ F(\theta) = \frac{1}{2} \left[ \cos^2 \theta \sin \theta + \cos^2 \theta \right] \]

where \( \theta \) indicates the Bragg angle.

The relationship between the lattice parameter and the \( F(\theta) \) of the sample analyzed is seen in Fig 3. All peaks are plotted to correspond to the values of ‘a’ denoted as lattice parameter where it was reckoned from the extrapolation straight line plotted from the Nelson-Riley function to \( \theta \) values of 0 to 90 degree in \( F(\theta) \) function.

The apparent density \( (\rho_a) \) of cylindrically shaped pellets was calculated using the given equation[20]

\[ \rho_a = \frac{m}{\pi r^2 h} \]  \hfill (3)

Here ‘r’, ‘m’ and ‘h’ denotes the radius, mass, and pellet’s thickness.

The ideal consistency\( (\rho_i) \) of the operative sample has been determined from the equation [20]

\[ \rho_s = \frac{ZM}{N} \]  \hfill (4)

Here Avogadro’s number is N ,themolecular’s weight is M and Z which is 8 for the spinel cubic structure stands for the number of the molecule per unit cell.

In this work, Porosity is also calculated from the given equation [20]

\[ P = 1 - \frac{\rho_a}{\rho_x} \]  \hfill (5)

Rising in divalent ions\( (Mg^{2+}, Zn^{2+}, Cu^{2+}, Mn^{2+}) \) in the spinel ferrites, the ferrite lattice parameter is predicted to increase. In octahedral B-sites and tetrahedral A-sites, the physical and magnetic properties of ferrites depend to a large degree on the distribution of cations. [21]. It is well understood that the lattice constant increases proportionally with the rise of the ionic radius. The lattice parameter was stated to obey the linearity rule of Vegard’s law [22] from sample-1 to sample-4. As the unit cell has increased as replaced by ions of greater ionic intensity, this improvement can be due to the ionic size difference. Although the ionic radius of \( Zn^{2+} \) (0.82Å) is greater than \( Mg^{2+} \) (0.78Å), it is predicted that the replacement will increase the lattice constant. Thus the study of fundamental properties such as Curie temperature and magnetization becomes possible with increased distance between the magnetic ions, and this distance increases with the presence of larger ions in the ferrite lattice. Values of the lattice constant of \( MgFe_2O_4 \) and \( Mg_{0.9}Zn_{0.1}Fe_2O_4 \) are 8.36Å [23] and 8.40Å. For \( Mg_{0.35}Cu_{0.2}Zn_{0.45}Fe_2O_4 \), the lattice constant increases marginally relative to \( Mg_{0.35}Cu_{0.2}Zn_{0.45}Fe_2O_4 \) due to incorporation of \( Cu^{2+} \) (0.78Å), \( Zn^{2+} \) (0.82Å). The lattice constant also increases for \( Mg_{0.7}Zn_{0.3}Mn \) than \( Mg_{0.7}Zn \) due to incorporation of \( Mn^{2+} \) (0.70Å) [24] and \( Zn^{2+} \) (0.82Å) [25] dopants in the lattice.

**TABLE 2**

Structural entity of samples, i.e. the lattice parameter, density and porosity

<table>
<thead>
<tr>
<th>Samples</th>
<th>Lattice constant, a (Å)</th>
<th>Bulk density, ( \rho_b ) (gm/cm(^3))</th>
<th>X-ray density, ( \rho_x ) or ( \rho_m ) (gm/cm(^3))</th>
<th>Porosity, P%</th>
</tr>
</thead>
<tbody>
<tr>
<td>( MgFe_2O_4 )</td>
<td>8.36</td>
<td>4.42</td>
<td>4.89</td>
<td>11.65</td>
</tr>
<tr>
<td>( Mg_{0.9}Zn_{0.1}Fe_2O_4 )</td>
<td>8.40</td>
<td>4.51</td>
<td>4.92</td>
<td>8.33</td>
</tr>
<tr>
<td>( Mg_{0.35}Cu_{0.2}Zn_{0.45}Fe_2O_4 )</td>
<td>8.41</td>
<td>4.65</td>
<td>5.01</td>
<td>7.18</td>
</tr>
<tr>
<td>( Mg_{0.35}Cu_{0.2}Zn_{0.45}Mn_{0.06}Fe_{1.94}O_4 )</td>
<td>8.42</td>
<td>4.78</td>
<td>5.07</td>
<td>5.71</td>
</tr>
</tbody>
</table>

**Fig. 3** Lattice parameter variance with Nelson-Riley method for all experiments

**Fig. 2** XRD Pattern of \( MgFe_2O_4, Mg_{0.9}Zn_{0.1}Fe_2O_4, Mg_{0.35}Cu_{0.2}Zn_{0.45}Fe_2O_4 \), and \( Mg_{0.35}Cu_{0.2}Zn_{0.45}Mn_{0.06}Fe_{1.94}O_4 \) ferrites.

**Fig. 4** Variation of density with different ferrite samples
The magnetic properties can also be determined by obtaining density of ferrite. By increasing the density of ferrites, elevated permeability can be achieved. The theoretical density is derived from the obtained lattice parameter, and the bulk density is calculated from the mass and volume ratio of all measured samples. A large rise in the bulk density is found in Fig.4 and Table 2 with the replacement of the material of Zn\(^{2+}\), Cu\(^{2+}\) and Mn\(^{2+}\). Sometimes the bulk density is observed to be less than the X-ray density. This may contribute to the presence of pores created and shaped during the sample preparation or sintering process. With the compound of Zn\(^{2+}\), Cu\(^{2+}\) and Mn\(^{2+}\), the porosity values of samples are greatly decreased. An indication can be found that in the densification of materials, these ions may support.

### 4.3 SEM MICROSTRUCTURE

In order to determine the microstructure of our prepared samples and calculate the average grain size, the scanning electron microscope was used. The samples shall be represented by the SEM microstructure in Fig.5. Basically, the microstructure depends on the sintering temperature and the substitutions used in the samples as well. The temperature allowed the pores and grain limits to be minimized during the sintering process. The reduction in pores, as a result makes the sample thick. The magnetic properties of ferrite materials have governed the grain scale. Both the sample's grain size and porosity affect the magnetic properties. If it is possible to reduce the porosity within the grain boundary[27], net magnetization can be improved. Since the grain growth rate is incredibly high, pores could also be left behind by increasingly changing grain borders, resulting in pores trapped within the grains. This intra-granular porosity, contributing to weak magnetic properties, is really difficult to remove. The sample influences the change in the size of the crop. The scale of the grain represents the existence of additional or less area for grain boundaries. Porosity may also be closely correlated with borders, since porosity can be reduced. Crop development is closely correlated with the mobility of grain boundaries. The mean grain size was obtained using the process of linear interception [28] and is shown in Table 3. As seen in Fig 5 and Table 3, the microstructure of the ferrite samples is strongly dependent on the amount of CuO present in the samples. By developing a liquid phase during sintering, the microstructure of the Mg-Zn ferrites is influenced by CuO. As a consequence of its grain boundary segregation [29], it facilitates grain growth by increasing the inter-diffusion cation density. Grain growth occurs during the sintering of the liquid phase by a dissolving/solution-precipitation process. Tiny grains are less stable than massive grains, energetically, owing to their larger individual surface areas. As a result, within the liquid-phase layers, small grains would be dissolved. Precipitation will occur after a critical threshold is approached by the concentration of the dissolved phase. This suggests that larger grains are growing at the expense of smaller grains. It appears that small grains need to "swim" to combine through a barrier (liquid-phase layer) with an outsized grain. It is noted that an increase in the amount of Cu content results in an increase in the grains' liquid-phase layer coverage, and this is favorable for grain growth. Consequently, the total grain size increases as the divalent material increases.

**Table 3**

Grain size of the ferrite samples.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Average grain size(µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MgFe(_2)O(_4)</td>
<td>07</td>
</tr>
<tr>
<td>Mg(<em>{0.5})Zn(</em>{0.5})Fe(_2)O(_4)</td>
<td>12</td>
</tr>
<tr>
<td>Mg(<em>{0.35})Cu(</em>{0.20})Zn(_{0.45})Fe(_2)O(_4)</td>
<td>39</td>
</tr>
<tr>
<td>Mg(<em>{0.35})Cu(</em>{0.20})Zn(<em>{0.45})Mn(</em>{0.06})Fe(_1.94)O(_4)</td>
<td>42</td>
</tr>
</tbody>
</table>

### 4.4 TEMPERATURE (CURIE TEMPERATURE) DEPENDENCY ON PERMEABILITY

For the toroid-shaped samples, Fig.6 demonstrates the temperature-dependence of initial permeability (µ'). It is found that the permeability increases when the temperature increases, and when the magnetic state of the ferrite samples varies from ferromagnetic to paramagnetic, it suddenly decreases above the Curie temperature, indicating that increasing thermal activation breaks the parallel alignment of the elementary magnets (spontaneous magnetisation). According to Globus [30], the sharpness of the permeability decrease at the Curie point may be used as an indicator of the degree of compositional homogeneity. As seen in Fig.6, the current ferrites display a strong degree of homogeneity. It is possible to express the difference of µ' with temperature as follows. The constant of anisotropy (K\(_{\alpha}\)) and saturation magnetization (M\(_{\alpha}\)) can be determined by obtaining the magnetic properties. If it is possible to express the difference of µ' with temperature as

\[
\mu' \propto \frac{M_\alpha^2 + D}{K_{\alpha}}
\]

Where M\(_\alpha\) is the saturation magnetization, D is the grain diameter, µ' at the temperature at which K\(_{\alpha}\) disappears, it must indicate a limit.
A good thermal stability of initial permeability for Mg-Zn, Mg-Cu-Zn ferrites can be seen from Fig.6, but the plateau in the $\mu'$-T curves indicates low thermal stability of ferrites Mg and Mg-Cu-Zn-Mn. The structure of the $\mu'$-T curve greatly depends on the composition and preparation conditions for the polycrystalline samples [32-33]. $T_c$ is the property of the Curie temperature that is important for inductor applications and highly sensitive to composition. The ferrite curie temperature is the temperature of transformation beyond which the ferrimagnetic substance becomes paramagnetic. The temperature of the Curie gives a notion of the amount of energy needed to disrupt the long-range order within the substance. From the $\mu'$-T curve, $T_c$ of the studied ferrite system has been calculated.

![Image](image_url)

**Fig. 6 Temperature dependence of real permeability for the ferrite samples**

The intensity of the interaction of the A-B exchange is the point on which the temperature of the Curie is primarily dependent. It is well known that the Curie temperature decreases as diamagnetic ions are added into the ferrite sub-lattice [34]. The change in $T_c$ can be related to the change in a A-B exchange interaction as a result of the change in the cation distribution between A and B sub-lattices due to divalent replacement. Divalent substitution only effectively weakens the A-B interchange relationship. Due to this reduced contact of A-B exchange with divalent (Zn$^{2+}$, Cu$^{2+}$, Mn$^{2+}$) material, the Curie temperature is expected to decrease. By adding non-magnetic ions, the number of bonds or linkages between the magnetic ions that determine the magnitude of the Curie temperature [35] is diminished. The temperature of the curie is given in Table 4 for all the samples.

![Image](image_url)

**Fig. 7 Hysteresis curves of the samples MgFe$\text{O}_4$, Mg$_{0.5}$Zn$_{0.5}$Fe$_2$O$_4$, Mg$_{0.35}$Cu$_{0.20}$Zn$_{0.45}$Fe$_2$O$_4$, and Mg$_{0.35}$Cu$_{0.20}$Zn$_{0.45}$Mn$_{0.06}$Fe$_{1.94}$O$_4$ ferrites.**

### 4.5 Field Dependence of Magnetization by VSM

The Vibrating Sample Magnetometer is a compact and sensitive tool invented by S to measure magnetic properties.

### Table 4

Data for Curie temperature ($T_c$) of the samples.

<table>
<thead>
<tr>
<th>Samples</th>
<th>$T_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MgFe$\text{O}_4$</td>
<td>375</td>
</tr>
<tr>
<td>Mg$<em>{0.5}$Zn$</em>{0.5}$Fe$_2$O$_4$</td>
<td>97</td>
</tr>
<tr>
<td>Mg$<em>{0.35}$Cu$</em>{0.20}$Zn$_{0.45}$Fe$_2$O$_4$</td>
<td>95</td>
</tr>
<tr>
<td>Mg$<em>{0.35}$Cu$</em>{0.20}$Zn$<em>{0.45}$Mn$</em>{0.06}$Fe$_{1.94}$O$_4$</td>
<td>107</td>
</tr>
</tbody>
</table>

As the sample is vibrated near it, Fonner which is centered on the flux shift in a coil. To constantly calculate the magnetic properties of the specimen as a function of field and temperature, a novel meter called the Vibrating Sample Magnetometer (VSM) is used. In this sort of magnetometer, in an area surrounded by several pick up coils, the sample is vibrated up and down. Therefore, the magnetic sample functions as a time-changing magnetic flux that varies within a selected defined area. It is to be understood from Maxwell’s law that a duration differs, An electric field is followed by magnetic flux, and hence the field produces a voltage in pickup coils. The alternating voltage signal is processed using a control device unit that tests the magnetization in order to extend the signal-to-noise ratio. The samples measure the room temperature magnetic hysteresis loop and the findings of the samples MgFe$\text{O}_4$, Mg$_{0.5}$Zn$_{0.5}$Fe$_2$O$_4$, Mg$_{0.35}$Cu$_{0.20}$Zn$_{0.45}$Fe$_2$O$_4$, and Mg$_{0.35}$Cu$_{0.20}$Zn$_{0.45}$Mn$_{0.06}$Fe$_{1.94}$O$_4$ are shown in Fig.7. No apparent hysteresis effect is seen by the hysteresis loops. Both samples had low coercivity levels, which meant that all samples belonged to the soft ferrite family.

### Table 5

Data for Saturation Magnetization (Ms), Coercivity (Hc), Ramanent Magnetzation (Mr) and Squarness(S).

<table>
<thead>
<tr>
<th>Samples</th>
<th>$M_s$(emu/g m)</th>
<th>Hc(oe)</th>
<th>Mr(emu)</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>MgFe$\text{O}_4$</td>
<td>25</td>
<td>28.48</td>
<td>0.035</td>
<td>0.09</td>
</tr>
<tr>
<td>Mg$<em>{0.5}$Zn$</em>{0.5}$Fe$_2$O$_4$</td>
<td>45</td>
<td>16.07</td>
<td>0.030</td>
<td>0.03</td>
</tr>
<tr>
<td>Mg$<em>{0.35}$Cu$</em>{0.20}$Zn$_{0.45}$Fe$_2$O$_4$</td>
<td>48</td>
<td>0.564</td>
<td>0.694</td>
<td>0.40</td>
</tr>
<tr>
<td>Mg$<em>{0.35}$Cu$</em>{0.20}$Zn$<em>{0.45}$Mn$</em>{0.06}$Fe$_{1.94}$O$_4$</td>
<td>54</td>
<td>15.23</td>
<td>0.016</td>
<td>0.01</td>
</tr>
</tbody>
</table>
The magnetization curves (M-H) of room temperatures are shown in Fig.8 as a function of the field. For the samples at room temperature, saturation magnetization Ms as shown in Table 5. It is observed that with increasing divalent content, saturation magnetization improves (Mg-Zn, Mg-Cu-Zn, Mg-Cu-Zn-Mn). In terms of the different exchange interactions, such as A-B, A-A, and B-B, the observed disparity in saturation magnetization, which depends on the distribution of magnetic and non-magnetic ions at the A and B sites, may be explained. It is understood that the A-B interaction is the strongest and that the B-B and A-A interactions are dominant. In this multi-cationic complex system, the difference in saturation magnetization with various divalent concentrations can be due to the re-arrangement of the cation distribution between the A and B sub-lattices. The stable ions of $Zn^{2+}$ indicate a preference for the spinel lattice tetrahedral (A-sites)[36] and $Fe^{3+}$ions in the Mg-Zn ferrite partly occupy A-sites and B-sites[37]. On $Mg^{2+}$ions, most B-sites are located and a small fraction migrates to A-sites[38]. Saturation magnetization is given by $M_s = M_B - M_A$ according to Nel's model of ferrimagnetism for two sub-lattice[39], where $M_B$ represents the octahedral and $M_A$ represents tetrahedral sub-lattice magnetization. The improvement in the value of M is due to the fact that $Cu^{2+}$ ions ideally appear to go to the B-sites by replacing $Mg^{2+}$ions and just a slight increase in the B-sites’ magnetic moment in order to increase the net magnetic moment.A maximum value of 54 emu/gm of Mg-Cu-Zn-Mn ferrite is obtained by saturation magnetization.

5 CONCLUSION

The variation in composition in X-ray diffraction confirms the spinel structure of the ferrite samples which exhibits significant improvement in bulk density of Mg-ferrites. And there is an improved grain growth and grain size. In this work, the sharp fall of $\mu$ was found in samples that reflect the strong homogeneity of the samples. The introduction of $Zn^{2+}$, $Cu^{2+}$ and $Mn^{2+}$ ions causes a decrement in Curie temperature. The increment in divalent content causes the slightest increment in saturation magnetization of samples.

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