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Study of electrical properties of Cu-Zn ferrite with Si additive

G. Uzma*

Department of Physics, University of Wah, Wah Cantt 04750, Pakistan

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Abstract

The effect of Si additive on the electrical resistivity measurements of Cu-Zn ferrites was investigated and then used to calculate the activation energy and drift mobility of all the samples. The series was prepared using the conventional ceramic double sintering process for $x = 0.66$, 0.77, 0.88, 0.99, and X-ray diffraction (XRD) measurements were taken to confirm the formation of ferrite structure. The improved values are attributed to the presence of Si, which can effectively perk up the resistivity. The room temperature dc resistivity decreases with increasing Cu content, which may be due to the $Cu^{+2} \rightarrow Cu^{+1}$ transition. The dc resistivity as a function of temperature range from 303 to 453 K was found to decrease with increasing temperature revealed semi conducting behavior. The results obtained explained that activation energy, E_p, decreases by increasing Cu content x, whereas mobility contradicts this result. It has also been pragmatic that the samples having higher resistivity have low mobility and mobility increases by increasing Cu content x.

Key words: ferroelectrics, Cu-Zn ferrite, silicon additive, semiconductors, electrical properties

1. Introduction

Ferrites are soft ferromagnetic materials having low magnetic coercivity and high resistivity values and small eddy current loss in high frequency operation. High electrical resistivity and good magnetic properties make these ferrites an excellent core material from the technological applications point of view [1, 2].

Ferrites have higher resistance than metals by several orders of magnitude and they are also regarded as very structure-sensitive materials [3]. It is a well-known fact that the properties of ferrite materials are strongly influenced by the materials composition and microstructure, but, in addition, the sintering conditions employed and the impurity levels present in or added to these materials also change their properties [1, 4–6]. The properties of crystalline matrix, either porous or not, have been studied in ferrite/SiO_2, ferrite/resin, etc. for different systems of compositions [1, 7], and electrical resistance can be improved further by using these different techniques. Especially the electrical resistivity of copper ferrite was increased by substituting divalent ions (Ni^{2+} or Cd^{2+}) [8, 9], trivalent ions (Cr^{3+}) [10] and tetravalent ions (Ti^{4+}) [11]. Therefore, it was of interest in the present article to produce Cu-Zn ferrites at comparatively low cost with improved electrical properties using locally available low cost Fe_2O_3 having 0.5 wt.% of Si as an additive. The addition of Si is carried out in order to introduce the influence of grain boundary phases that are non-magnetic and also affect the grain growth, consequently increasing the resistivity [5, 6].

2. Experimental details

Ferrite samples with compositions $Cu_xZn_{1-x}Fe_2O_4$ ($x = 0.66$, 0.77, 0.88 and 0.99) were prepared in polycrystalline form by high temperature solid-state reaction method. The compositions, $Cu_xZn_{1-x}Fe_2O_4$, were prepared and X-ray diffraction (XRD) patterns as shown in Fig. 1 were taken to identify the phases formed and to confirm the completion of the chemical reaction by using Rigaku XRD D/MAX-IIA diffract meter using Cu Kα radiation with scanning speed of $1°$ ($2\,\theta\,min^{-1}$), details are reported in an earlier pub-

* Tel./fax: 0092-51-905523255; e-mail address: uzigh@yahoo.com

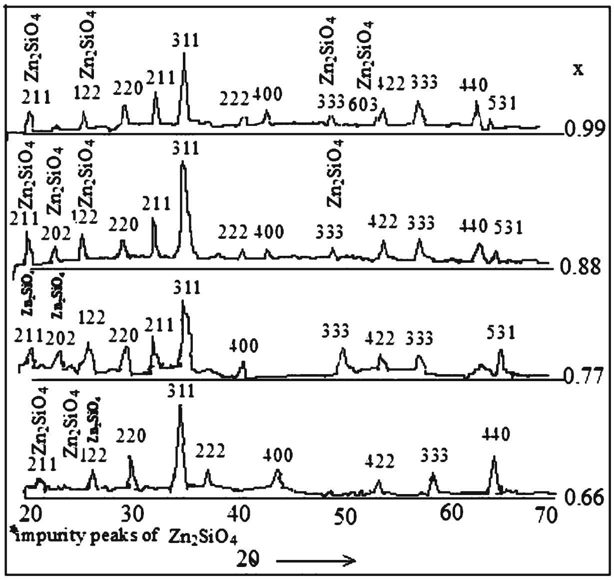

Fig. 1. XRD patterns of Cu-Zn ferrites ($Cu_xZn_{1-x}Fe_2O_4$) with $x = 0.66$, 0.77, 0.88, 0.99.

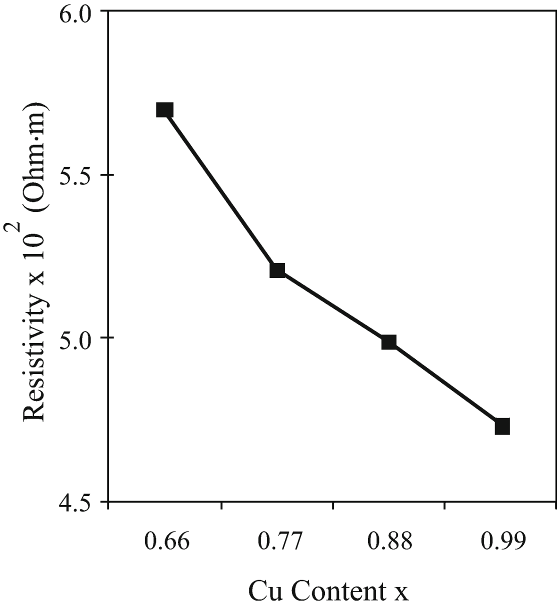

Fig. 2. Plot of resistivity versus Cu concentration x.

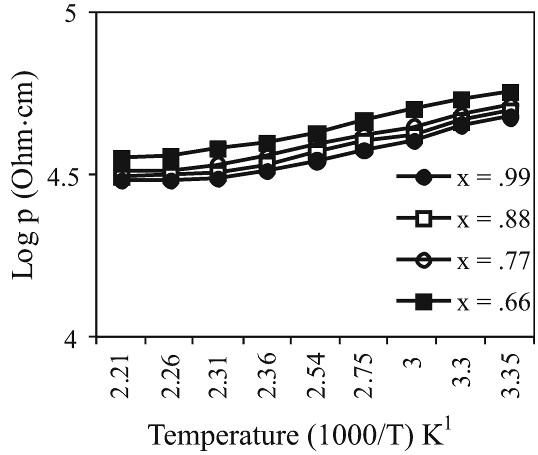

Fig. 3. Arrhenius plots of Cu-Zn ferrite.

lication [12]. In the present work, the surface of the pellets was cleaned by grinding on SiC paper in order to remove any contamination and then used to study the room temperature dc resistivity, measured by two probe-methods, and calculate the activation energy and drift mobility of Cu-Zn ferrite.

3. Results and discussion

3.1. Resistivity versus Cu concentration x

In the present study, room temperature DC resistivity of all these samples was measured by two probe-methods and is plotted in Fig. 2, as a function of Cu content. It has been observed that the resistivity (ρ) decreases from 5.70×10^4 to 3.77×10^4 Ω cm as the concentration of Cu increases from $x = 0.66$ to 0.99. This decrease in the resistivity may be due to the reason that Cu is less resistive ($\rho = 1.70\ \mu\Omega$ cm) than Zn ($\rho = 5.92\ \mu\Omega$ cm) [13, 14]. This decrease with increasing content of Cu^{2+} ions may also be attributed to the fact that in the case of Cu-Zn ferrite, B-sites are occupied by both Cu^{2+} and Fe^{3+} ions, whereas Fe^{2+} and Zn^{2+} are in A-site. The conduction mechanism in ferrite is considered as the electron hopping between Fe^{2+} and Fe^{3+} in B-site. In Cu-Zn ferrite, $Fe^{3+} + Cu^{1+} \Leftrightarrow Fe^{2+} + Cu^{2+}$, equilibrium may exist during sintering. Under oxidizing conditions, the tendency is towards the right to increase the probability of electron hopping. With increasing the sintering temperature more Cu^{1+} ions are oxidized to Cu^{2+}, resulting in decrease of resistivity. We achieved better values of resistivity, may be due to the presence of Si that did not contribute to conduction but acted as a scattering center at B-sites.

3.2. Arrhenius plots of Cu-Zn ferrites

The variation of temperature dependent dc resistivity measurement in the temperature range 303–453 K is depicted in Fig. 3. This follows the exponential relationship (Arrhenius plot), which shows that resistivity decreases with increasing temperature. This agrees well with the results observed in the mixed Cu-Zn spinal ferrite [15–18] accordingly, the ferrite system under investigation over the studied range of

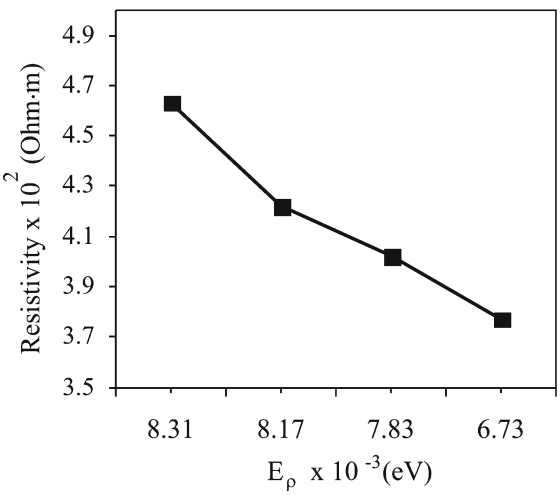

Fig. 4. Plot of resistivity versus activation energy.

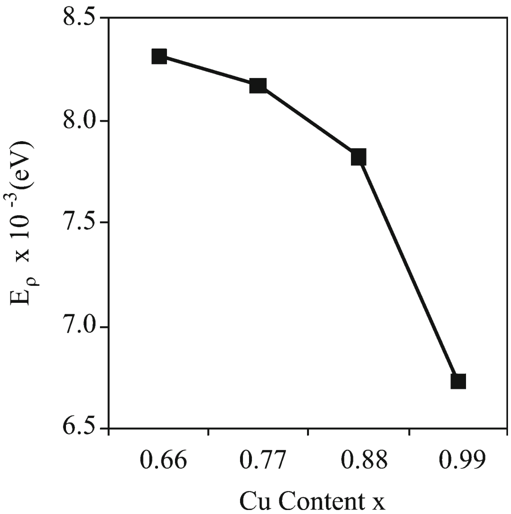

Fig. 5. Plot of activation energy versus Cu content x.

temperature behaves as semi-conducting material. It may be, therefore, said that these ferrites have semi--conductor behavior (the formation of ferrite is confirmed).

3.3. Activation energies versus resistivity and Cu concentration x

The activation energy has been calculated using the following relation [15]:

$$\rho = \rho_{\infty} \exp^{(E_{\mathrm{p}}/kT)}, \tag{1}$$

where ρ is resistivity, ρ_{∞} is resistivity extrapolated to $T = \infty$, E_{p} is activation energy, K is Boltzmann's constant and T is absolute temperature. The values of activation energies plotted against resistivity and Cu concentration x are shown in Figs. 4 and 5, respectively. It can be observed that by decreasing the resistivity and increasing the Cu content x, the values of activation energies are decreased, because it can also be seen that samples having low resistivities have low activation energies and vice versa as predicted by Islam and Shabasy in their work [19, 20].

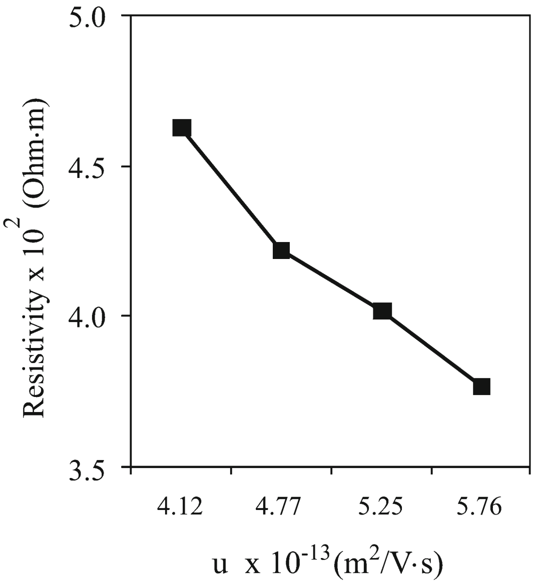

Fig. 6. Plot of drift mobility versus resistivity.

3.4. Drift mobility versus Cu concentration and temperature

Drift mobility of all the samples has been calculated using the equation [15]:

$$\mu = 1/ne\rho, \tag{2}$$

where e is the charge on electron, ρ is resistivity and n is the concentration of charge carriers, which can be calculated from the following equation [15]:

$$n = Na\, \rho_{\mathrm{a}} P/M, \tag{3}$$

where M is the molecular weight, Na is the Avogadro's number, ρ_{a} is the density of sample, and P is the number of iron atoms in the chemical formula of the oxide. The variation of mobility with respect to resistivity and Cu concentration x is shown in Figs. 6 and 7, respectively. It can be seen that the samples having higher resistivity have low mobility and mobility increases by increasing Cu content x [15, 19].

4. Conclusions

The main objective of this study was to produce

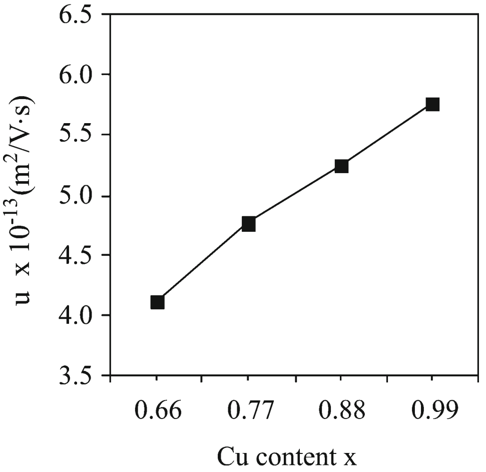

Fig. 7. Plot of drift mobility versus Cu concentration x.

ferrites by using cost-effectively feasible manufacturing process and selecting technically practicable compositions. Therefore we have selected low cost iron oxide with 0.5 wt.% of Si as an additive having great control on electrical properties of sintered bodies. The values obtained are better than those for the samples prepared using pure Fe_2O_3 powder. This is noteworthy of the present research and provides expedient and inexpensive method for preparation ferrites of better quality which can be used for industrial applications.

A decrease in room temperature resistivity and E_p by increasing Cu content could be related to the shifting of Fe^{+2} ions from octahedral to the tetrahedral sites and $Cu^{+2} \rightarrow Cu^{+1}$ transition. The temperature dependent resistivity in the temperature range 303–453 K also decreases by increasing temperature attributed to the semi-conducting behavior of the Cu-Zn ferrites. The samples having low resistivity have lower activation energies and vice versa. It has also been perceived that the samples having higher resistivity have low mobility and mobility increases by increasing Cu content x.

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