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# Electrical Conductivity of Sn Substituted Mg - Zn Ferrites

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**Abstract:** ***The variation of electrical resistivity and thermo-emf with temperature has been studied for the ferrites with system*** $Mg_{0.7+x}$ $Zn_{0.3}$ $Sn_x$ $Fe_{2-2x}$ $O_4$ ***with x = 0.0, 0.1, 0.2 and 0.3. The x-ray diffraction data were used to confirm single phase formation and calculation of lattice parameters. It is observed that all the sample show n-type behavior. From conduction data it reveals that at low temperature conduction is due to impurity carriers, whereas at high temperature it is due to Polaron hopping mechanism.***

## 1. Introduction

Ferrites having spinel structure are ferromagnetic and have potential applications. High electrical resistivity and relatively easy preparation make these materials widely useful for the cores of intermediate and high frequency electromagnetic devices. Ferrites have vast applications from microwave to radio frequencies [1]. Therefore their study related to electrical properties is important. Discussion on the electrical properties of ferrites is usually based on the band structure or carrier hopping model. However, until now no conclusive theory has been formulated for the conduction mechanism in ferrites. In this paper, we report the electrical resistivity and thermoelectric power as a function of temperature of Sn substituted Mg-Zn ferrites.

## 2. Experimental

Samples with composition $Mg_{0.7+x}$ $Zn_{0.3}$ $Sn_x$ $Fe_{2-2x}$ $O_4$ with x = 0.0, 0.1, 0.2 and 0.3 were prepared by usual ceramic technique using AR grade oxides. It is mixed in proper proportions for the desired compositions and pre sintered at 800$^o$C for 10 hour in air. The pellets were made from the pre sintered powder. They were finally sintered at 1100 $^o$C for 24 hour and furnace cooled at the rate of 80 $^o$C / hour. The x-ray diffraction pattern of the samples was recorded using a Philips diffractometer. This revealed that all the samples were found to be single phase spinels..

The electrical measurements were carried out by means of two probe method. Silver paste was applied on both of the flat surfaces of the pellet for good electric contacts. A low but constant voltage was applied across the sample and current through the sample was measured as a function of temperature. The activation energy was calculated from the variation in resistivity with temperature using the formula

$$\rho = \rho_0 \exp(\Delta E/KT)$$

The Seebeck coefficient α was measured as a function of temperature and composition maintaining the temperature difference of 20 $^o$C. Details of measurement of electrical resistivity ρ and thermoelectric power are given elsewhere [2].

## 3. Results and Discussion

From x-ray diffraction pattern it was observed that all the samples were single phase [3]. The lattice constants are listed in table 1. The variation of log ρ with 1/T for all the compositions is shown in figure 1(a). The activation energies were calculated for different regions. The resistivities with temperature plots show three regions with two breaks. The slope of the second region changes at temperature which is nearly equal to Curie temperature. The conduction phenomenon in the first region of lower temperature is attributed to the impurities while conduction at high temperature is due to the polaron hopping. From the activation energies noted in table 1, it is seen that the energy in I region is less than 0.18 eV which decreases with increasing Sn. The activation energy is greater than 0.3 and 0.55 eV for the II and III region respectively that is feri region. These energies are higher than the ionization energy of donors or acceptors that is 0.1 eV and hence possibility of band type conductor is ruled out. This suggests that the polaron hopping mechanism is favored.

The Seebeck coefficient α is given by the relation

$$\alpha = \Delta V/\Delta T$$

Where ΔV – voltage measured across sample,
ΔT – temperature difference across sample


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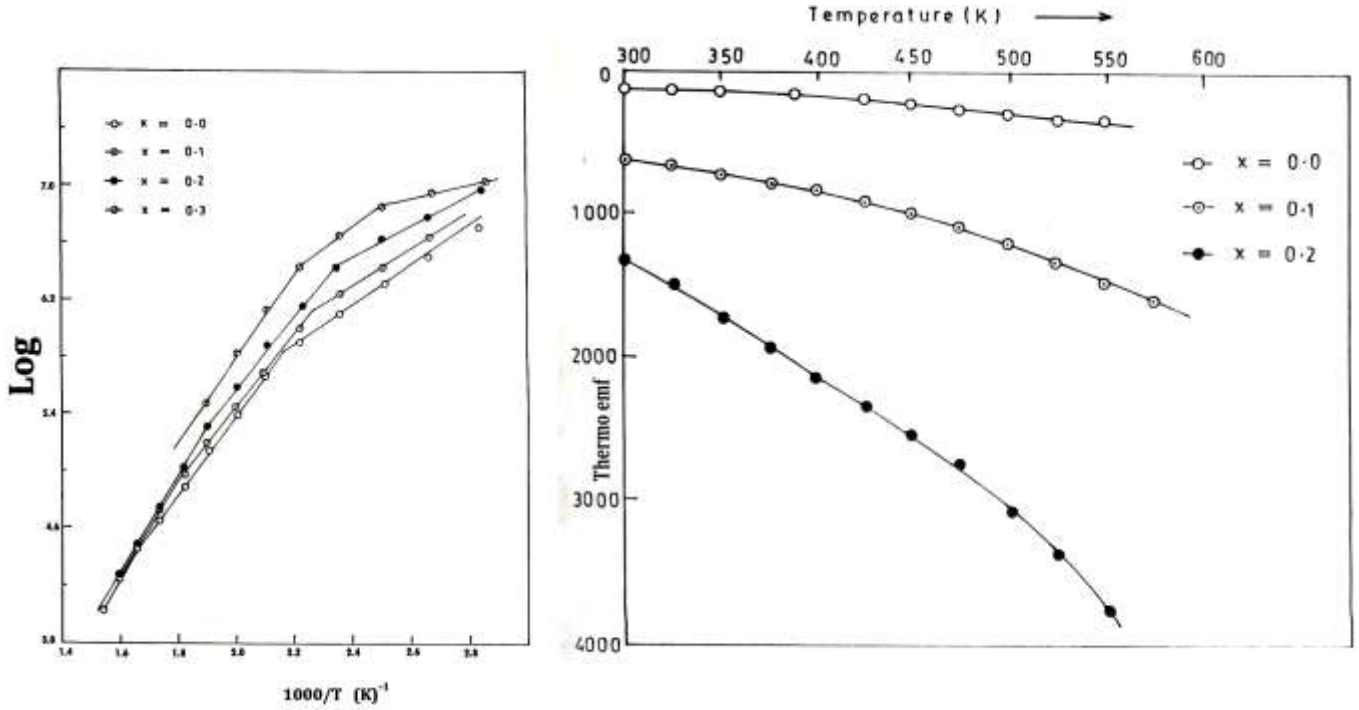



**Figure 1:** (a) variation of resistivity with temperature and (b) variation of thermo emf with temperature

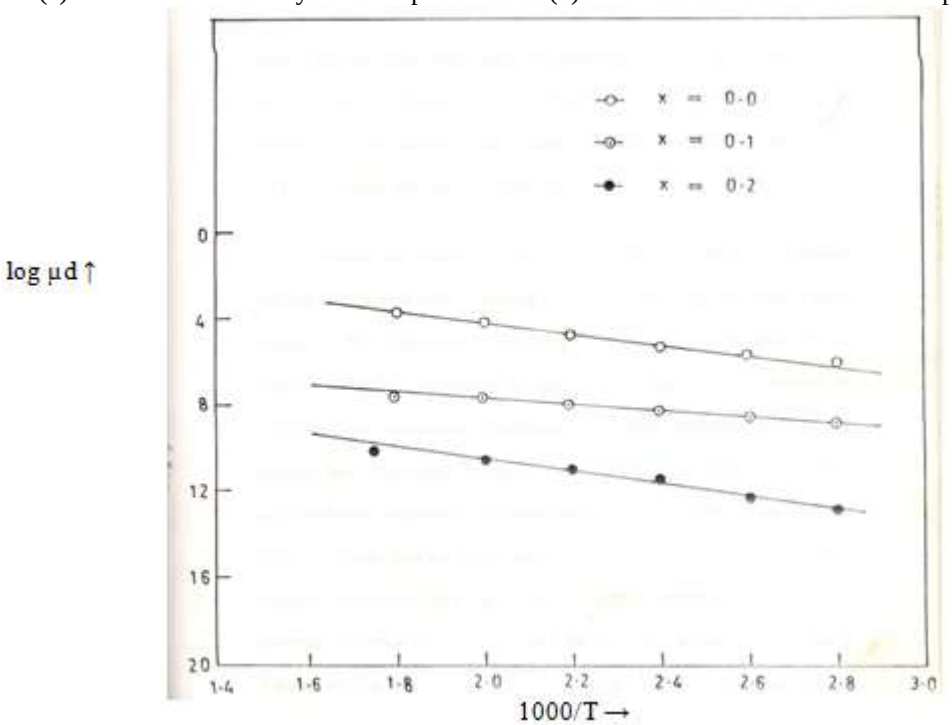



**Figure 2:** Variation of log μd with Temperature

Figure 1(b) shows the variation of Seebeck coefficient with temperature for all the samples. The feature for all the compositions is that the seeback coefficient values are negative over whole range of temperature indicating that the majority of charge carriers are electrons. It is also noted that the absolute value of seeback coefficient increases with increasing Sn. It is also observed that α is independent of temperature, which indicates there is no change in concentration of charge carriers. However the small variation in α is due to change in mobility of charge carriers.

Electrical resistivity in ferrites can be explained by Vervey-de Boer mechanism involved in electron exchange between ions of same element which are present in more than one valence state and are distributed randomly over crystallographicaly equivalent lattice sites{26}. Depending on the sintering conditions a number of such ions can be produced during preparation of such samples. It is also known that the partial reduction of the $Fe^{3+}$ to $Fe^{2+}$ can take place at elevated temperature. The formation of very small amount of $Fe^{2+}$ ions may also be expected owing to evaporation of Zn ions during sintering process{22}. Therefore in the present system the conduction is mainly due to $Fe^{2+}$ -- $Fe^{3+}$ transition, and majority carriers are n- type.


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Generally the conduction mechanism is explained on the basis of polaron hopping model. In the polaron hopping model just as in the case of transition metal oxides{28}. The conduction by uncorrelated hopping process is taken over by polarons which are characterized by large effective mass and low mobility of current carriers. Temperature dependence of electrical conductivity in such a case involves less temperature dependent concentration of carriers and is mostly associated with temperature dependent mobility. The activation energy observed from conductivity data are greater than 0.3 eV and 0.55 eV for II and III regions respectively which are much higher than the ionization potential 0.1 eV and for electronic transition 0.2 eV, which favours that the conduction is due to polaron hopping model. This is also supported with thermoemf data which is also temperature independent. Therefore we conclude that the electrical conductivity in the ferrites is due to polaron hopping mechanism. Bashkirov at al [34] have applied this formula for Mn-Zn ferrites of different compositions and have ckassified ferrites as degenerate semiconductors if the thermoemf is independent of temperature. The temperature dependent thermo-emf is characteristic of nondegenerate semiconductors. In present system it is observed that thermo emf is nearly independent of temperature and therefore they are degenerate semiconductors.

The mobility values are calculated using the values of α and ρ and using the relation

$$\mu_d = [\exp(\alpha/\{2.3(k/e)\}] / (2N_o e\rho)$$

The variation of mobility with temperature is shown in figure 3 and activation energy from the mobility are calculated by relation,

$$\mu_d = \mu_o \exp(-\Delta E/KT)$$

Estimated values are noted in the table. The activation energy from mobility and from resistivityi in ferri region values are nearly equal. This confirms that the conduction phenomenon from the present system is due to the polaron hopping.

**Table 1:** Lattice constants, activation energies from conductivity and mobility of given samples.

| Content (x) | Lattice Parameter ($A^o$) | Activation energy from conductivity $\Delta E_1$ (eV) | Activation energy from conductivity $\Delta E_2$ (eV) | Activation energy from conductivity $\Delta E_3$ (eV) | Activation energy from mobility (eV) |
|---|---|---|---|---|---|
| 0.0 | 8.390 | 0.18 | 0.56 | 0.79 | 0.54 |
| 0.1 | 8.413 | 0.14 | 0.49 | 0.63 | 0.44 |
| 0.2 | 8.432 | 0.16 | 0.43 | 0.57 | 0.38 |
| 0.3 | 8.452 | 0.09 | 0.31 | 0.55 | 0.34 |

## 4. Conclusion

For the present studied system, the conduction in the first region of lower temperature is due to the impurities while the conduction at higher temperature is due to the polaron hopping mechanism. All the sample show n type behavior. The variation of Seebeck coefficient with temperature for this system shows degenerate semiconducting type of behavior.

## 5. Acknowledgement

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