

DC resistivity and thermoelectric power in Ni–Cd ferrites

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MS received 3 January 1994; revised 12 April 1994

Abstract. The electrical resistivity and Seebeck coefficient for Ni–Cd ferrites have been studied as a function of temperature. The lattice constant of the phases have been evaluated from X-ray powder data. The thermoelectric power measurements indicate that the samples are *n*-type semiconductors and the conduction mechanism is interpreted on the basis of localized model of polarons.

Keywords. Ferrite: resistivity: thermoelectric power: polaron hopping.

1. Introduction

Ferrites having spinel structure are ferrimagnetic and have semiconductor properties of type *n* or *p* (Jonker 1959; Belov *et al* 1961). The factors specific to semiconductors with the super exchange interaction will be low carrier mobility, increase with temperature for the conductivity of the hopping type and correlation with magnetic state of the material (Methfessel and Mattis 1968). The conduction phenomenon in Ni-ferrite has been studied by many workers (Baszynski 1980; Guyot *et al* 1980). Parameters such as thermoelectric power and electrical resistivity are the most convenient to measure and suggest the conduction phenomenon. The present study is concerned mainly with experimental results for electrical conductivity and Seebeck coefficient of Ni–Cd ferrites.

2. Experimental details

Samples with composition $\text{Cd}_x\text{Ni}_{1-x}\text{Fe}_2\text{O}_4$ ($x = 0.0$ to 0.6) were prepared using standard ceramic technique. Analytical reagent grade CdO , NiO and Fe_2O_3 were mixed intimately in stoichiometric proportion and preheated in air at a temperature of 850°C for 10 h. Pellets were made from the pre-sintered powder. These were finally sintered at 1150°C for 24 h and furnace-cooled at the rate of $80^\circ\text{C}/\text{h}$. The X-ray diffraction patterns of the samples were recorded using a Philips diffractometer (type PW 1010). A Philips generator operated at 35 kV and 20 mA provided a source of Cu-K_α radiation (Ni-filtered). The density of the samples was measured by liquid immersion method. The electrical measurements were carried out by means of two-probe method. The electrical contacts were made ohmic using air-dried silver epoxy. Seebeck coefficient α was measured as a function of temperature and composition maintaining the temperature difference of $\approx 20^\circ\text{C}$. Details of measurement of electrical resistivity ρ and thermoelectric power are given elsewhere (Patil 1994).

3. Results and discussion

From diffraction patterns it was observed that all the samples were single phase. The lattice constants of spinel structure and measured densities are given in table 1. The lattice constant increases with increase of Cd content. This is in accordance with the large ionic radius of Cd (1.03 Å) compared to that of Ni (0.78 Å). From the table we notice that the measured density behaves as a wave with composition. This behaviour is characteristic of ceramic samples.

The variation of $\log \rho$ with $1/T$ for all the compositions is shown in figure 1. The activation energies are calculated for different regions by using the relation

$$\rho = \rho_0 \exp(\Delta E/kT), \quad (1)$$

Table 1. Compositional variation of lattice constant, measured density and activation energy of $\text{Cd}_x\text{Ni}_{1-x}\text{Fe}_2\text{O}_4$.

x	Lattice parameter a (Å ± 0.002)	Measured density (g/cm ³)	Activation energy from conductivity (eV ± 0.02)		Activation energy from mobility $\Delta E(\mu_d)$ (eV)
			ΔE_1	ΔE_2	
0.0	8.365	4.35	0.33	0.49	0.47
0.1	8.418	4.79	0.29	0.45	0.47
0.2	8.471	4.55	0.32	0.43	0.46
0.4	8.537	4.72	0.29	0.49	0.51
0.5	8.568	4.77	0.30	0.49	0.45
0.6	8.545	4.82	0.29	0.43	0.42

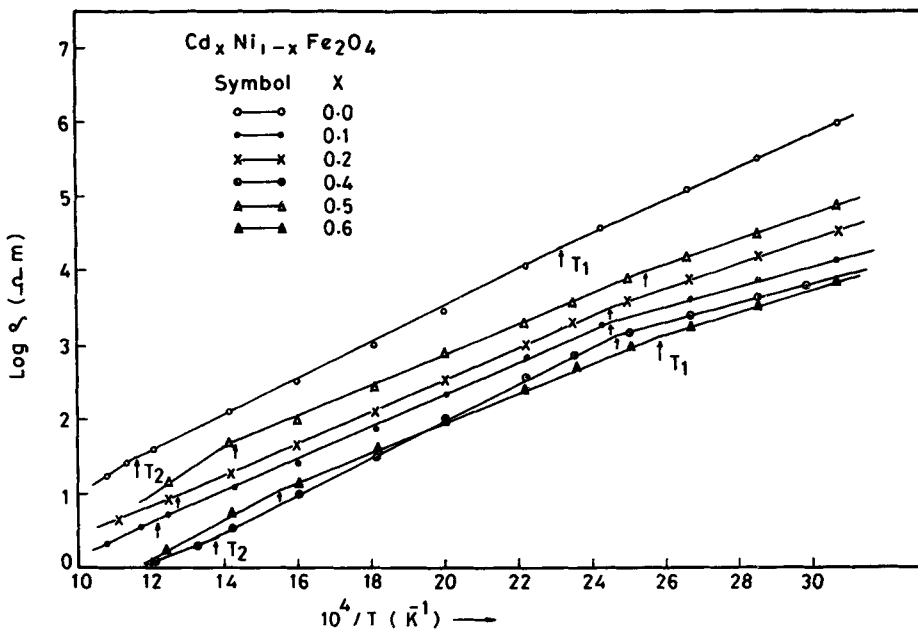


Figure 1. Variation of $\log \rho$ with $1/T$ for $\text{Cd}_x\text{Ni}_{1-x}\text{Fe}_2\text{O}_4$.

where ΔE is the activation energy, k the Boltzmann constant and T the absolute temperature. The activation energies in region I (< 400 K) are < 0.3 eV and in region II (> 400 K) they are > 0.45 eV.

The Seebeck coefficient (α) is given by the relation

$$\alpha = \frac{\Delta V}{\Delta T}, \quad (2)$$

where ΔV is the voltage measured across the sample and ΔT the temperature difference across the sample. Figure 2 shows the temperature variation of thermoelectric power (α) for $\text{Cd}_x\text{Ni}_{1-x}\text{Fe}_2\text{O}_4$ system. The common feature for all the compositions is that α is negative over the whole range of temperature, indicating that the charge carriers are electrons. For electronic conduction α can be given by

$$\alpha = 2.3 \frac{k}{e} \log \left(\frac{2N}{n} \right), \quad (3)$$

where N is the concentration of Fe^{3+} ions in the octahedral site, n the concentration of Fe^{2+} ions in the same site, and e the electronic charge. The temperature behaviour of $(2.3k/e)^{-1} \cdot \alpha$ obtained experimentally shows that the electron concentration is independent of temperature. However, at lower temperature (< 400 K), the α value increases slowly with temperature. The majority of charge carriers are electrons generated from Fe^{2+} ions which act as donor centres. The temperature dependence of α is mainly determined by n and this may be attributed to the predominance of impurity conduction in this region. Therefore conduction phenomenon in these ferrites is due to impurity conduction at lower temperatures while it is due to the polaron

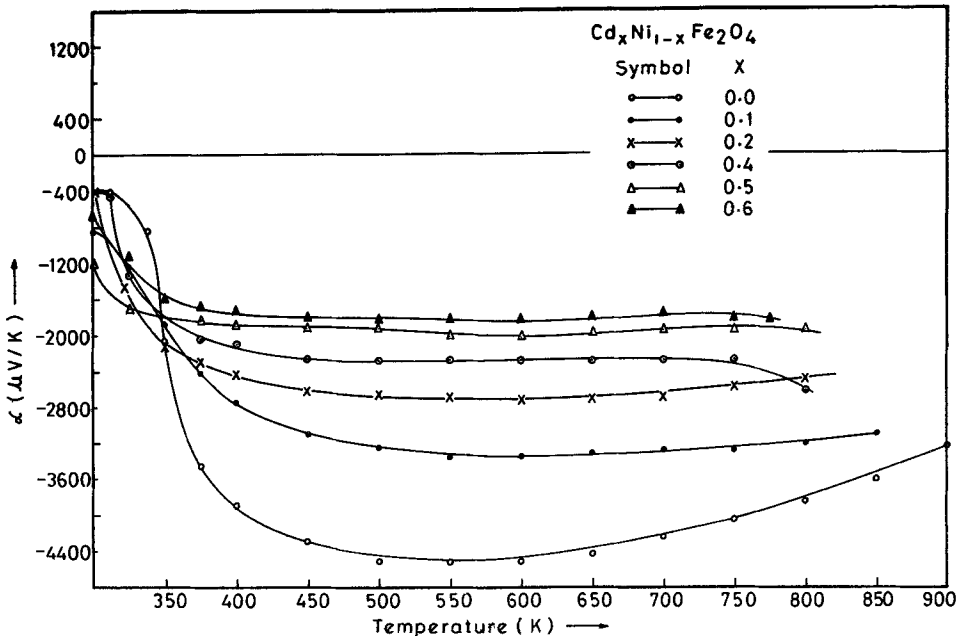


Figure 2. Variation of Seebeck coefficient (α) with temperature for $\text{Cd}_x\text{Ni}_{1-x}\text{Fe}_2\text{O}_4$.

hopping at higher temperature (> 400 K). There is strong experimental proof for the existence of polarons and their hopping process (Klinger 1975).

The drift mobility μ_d was calculated using the data of ρ and α and applying the method proposed by Ghani at different temperatures for all the compositions (Eatah et al 1987). The relation for drift mobility is given by

$$\exp\left(\frac{\alpha}{2.3 k/e}\right) / \rho = 2N_o e \cdot \mu_d, \quad (4)$$

where N_o is concentration of Fe^{3+} ions at octahedral site, and the other notations have their usual meanings. The plots of $\log \mu_d$ vs $1/T$ are shown in figure 3. It is observed that the drift mobility increases with increase of temperature. The activation energies obtained from these plots are noted in table 1. These values agree well with conductivity data (ΔE_2). The temperature dependence of ρ , α and μ_d suggests that the charge carriers in these samples can be described by localized model of conduction

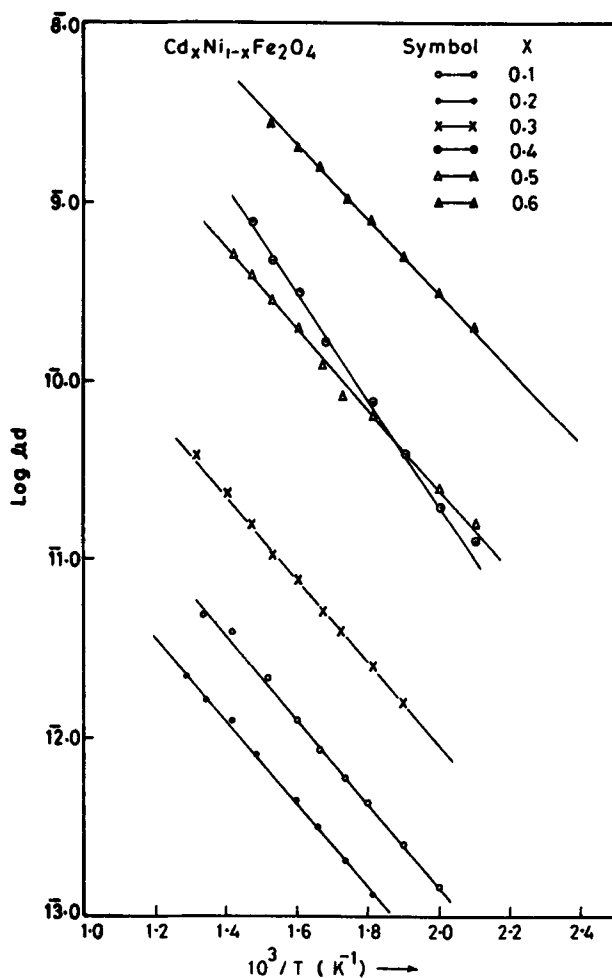


Figure 3. Variation of $\log \mu_d$ with $1/T$ for $\text{Cd}_x\text{Ni}_{1-x}\text{Fe}_2\text{O}_4$.

in ferrites. The temperature variation of conductivity in this case was mainly attributed to change of drift mobility with temperature rather than to the variation of charge carrier concentration. According to the localized model, the electrons are strongly localized on the cations. The localization may be attributed to electron–phonon interaction. An additional localization of electrons at Fe^{2+} ions may arise from inhomogeneous distribution of ions over octahedral sites in the spinel lattice (Austin and Mott 1969).

Acknowledgements

The authors wish to thank Prof. R N Patil for encouragement and useful discussion. One of the authors (MGP) is grateful to U G C for teacher fellowship.

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