PRAMANA
— journal of
physics

© Indian Academy of Sciences

Vol. 58, Nos 5 & 6
May & June 2002
pp. 787–789

ac Conductivity of mixed spinel $NiAl_{0.7}Cr_{0.7}Fe_{0.6}O_4$

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Abstract. ac Conductivity measurements are carried out across the metal to insulator transition in $NiAl_{0.7}Cr_{0.7}Fe_{0.6}O_4$. The low frequency data is analyzed using Summerfield scaling theory for hopping conductivity. The exponent of the scaling behavior has significantly different values in the conducting and insulating regimes. The hopping frequency and the zero frequency conductivity are found to increase with temperature, slowly in the metallic regime and rapidly in the insulating regime.

Keywords. Spinel; ac conductivity; frequency response.

PACS Nos 75.50.-y; 77.90.+k

1. Introduction

The nickel ferrite $NiFe_2O_4$ is an inverse spinel [1]. This spinel remains insulating at all temperatures and shows a paramagnetic to a collinear ferrimagnetic transition at Néel temperature $T_N \approx 850$ K. A metal–insulator transition is found, with insulating phase at higher temperatures in the Al and Cr co-substituted $NiAl_xCr_xFe_{2-2x}O_4$ spinels for $x \geq 0.5$ [2]. The metal to insulator transition temperature (T_p) is reported to remain nearly constant at 453 K for $x = 0.5$–0.7 samples and increases to 553 K for $x = 0.9$ sample. The insulator to metal transition is accompanied by a magnetic transition from paramagnetic to ferrimagnetic phase [2] which is similar to what is observed in layered perovskite oxides of 3d elements [3]. A change of collinear ferrimagnetic to non-collinear ferrimagnetic behavior is found at $x \sim 0.5$ [4]. A correlation between the insulator–metal transition and collinear–non-collinear magnetic structure change is therefore evident. With an aim to understand the mechanism responsible for such magnetic and transport behavior we have carried out ac-conductivity measurements and here we report the results of our preliminary study on the sample where $x = 0.7$.

2. Experimental

Polycrystalline samples are prepared by double sintering method from the constituent oxides of 99.9% purity. The oxides were mixed in stoichiometric proportions to yield the

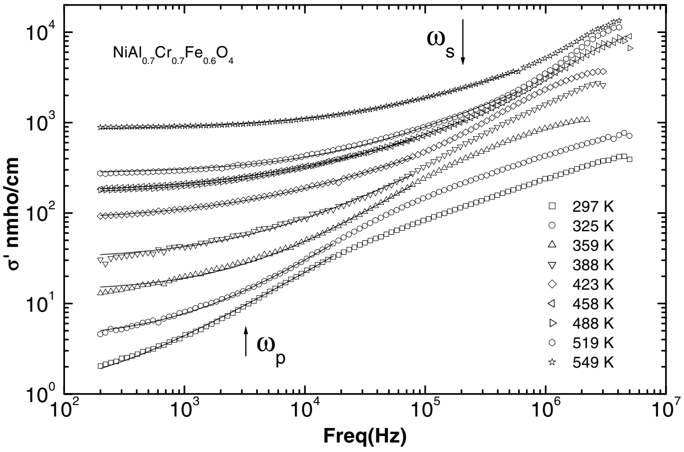

Figure 1. Real part of the ac conductivity as a function of frequency for various temperatures. The ω_p and ω_s indications are for 359 K data.

desired composition and then wet ground. The mixture was dried and pressed into pellets and fired at 1000° C for 24 h. The pellets were ground and pelletized again and heated in air at 1050°C for 24 h and then slowly cooled to room temperature at 2°C/min. Powder X-ray diffraction data was used to verify the single phase nature of the sample.

Real and imaginary parts of ac conductivity ($\sigma'(\omega)$ and $\sigma''(\omega)$ respectively) were measured on a disc-shaped sample of thickness 2.57 mm and area 0.8 cm^2. The measurements were carried out using a HP4194A impedence analyzer in a frequency range of 100 Hz to 10 MHz. The two faces of the disc were coated with silver paste for better contact with the electrodes. The temperature was varied from room temperature to 550 K using a heating element connected to a Eurotherm temperature controller. The temperature was measured using a Cromel Alumel thermocouple. The imaginary part (σ'') of the conductivity relates to dielectric constant of the material and is not discussed in this paper.

3. Results and discussion

The real part (σ') of the conductivity is shown in figure 1. The low frequency ($\sim$ 100 Hz) data do not follow the trend shown by the DC measurements [2] across the transition. Instead it shows a continuous increase of conductivity with temperature. The interesting feature to be noted in the log–log plot is that there are two characteristic frequencies involved in the conduction mechanism: the lower one (ω_p), above which the conductivity starts rising sharply and the upper one (ω_s) above which the conductivity saturates. This behavior has been observed in other compounds as well [5]. Both ω_p and ω_s increase with increasing temperature. The separation between them also increases with temperature.

This observed variation is as expected by Summerfield theory [6] for hopping conductivity. Summerfield theory for hopping conductivity predicts a scaling law for the low frequency ac conductivity which is given by $\sigma'(\omega) = \sigma(0)[1 + (\omega/\omega_p)^\beta]$. The low frequency is defined as the frequency up to midpoint between ω_p and ω_s. Accordingly, the low fre-

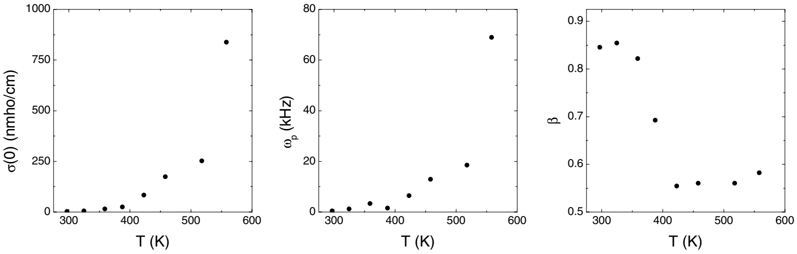

Figure 2. Parameters obtained by low frequency fit of the conductivity data (see text).

quency data was fitted to the above expression and the resulting parameters are shown in figure 2. The metal to insulator transition temperature (T_p), as indicated by the temperature dependence of these parameters is $\sim$ 425 K. It is apparent from the figure that ω_p increases monotonically with temperature. However, above T_p, the rate of increase is much higher. The same is true for $\sigma(0)$. The exponent (β) has predominantly two values viz. $\sim$ 0.85 below T_p and $\sim$ 0.56 above. Though the conductivity (σ') data (figure 1) by itself does not show any marked difference across T_p, the fitted parameters show clear change around the metal to insulator transition temperature.

4. Conclusion

We have measured the ac conductivity of Al and Cr co-substituted ferrite $NiFe_2O_4$. The low frequency data show that the conductivity mechanism is due to hopping and explained well by the scaling theory of Summerfield.

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