Dispersion of dielectric constant and resistivity of $\text{Cu}_x\text{Zn}_{1-x}\text{Fe}_2\text{O}_4$ samples

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Abstract. $\text{Cu}_x\text{Zn}_{1-x}\text{Fe}_2\text{O}_4$ samples exhibit dispersion of dielectric constant, $\tan\delta$ and resistivity in the frequency range of 1 kHz to 50 MHz. The dispersion exhibited is in general accord with Koops' model. However, the details of the conducting and non-conducting regions must be taken into account when composition tends to change interrelationship between the elementary capacitor resistor circuits.

On quenching these samples from 800°C the dielectric constant ϵ' showed an increase for CuFe_2O_4 and $\text{Cu}_{0.8}\text{Zn}_{0.2}\text{Fe}_2\text{O}_4$ samples. The dielectric constant of the remaining samples showed no influence on quenching. The compositional variation showed that the dielectric constant has higher value for the ferrite $\text{Cu}_{0.4}\text{Zn}_{0.6}\text{Fe}_2\text{O}_4$.

The results are explained on the basis of cation transfer.

Keywords. Dispersion; quenching; interfacial polarisation; dielectric constant.

1. Introduction

Ferrites show abnormally high dielectric constant and dispersion of dielectric constant and resistivity (Kamiyoshi 1951). The dispersion is explained by Koops (1951) and Moltgen (1952) to be due to inhomogeneous dielectric structure suggested by Maxwell (1873) and Wagner (1915).

The Koops model does not give details of the conducting and non-conducting regions. These studies are therefore essential.

In the present paper we report our studies on dielectric constant, resistivity and $\tan\delta$ for $\text{Cu}_x\text{Zn}_{1-x}\text{Fe}_2\text{O}_4$ samples in the frequency range of 1 kHz to 50 MHz. The dielectric constants of the samples of $\text{Cu}_x\text{Zn}_{1-x}\text{Fe}_2\text{O}_4$ quenched from 800°C are also presented.

2. Experimental

Samples of $\text{Cu}_x\text{Zn}_{1-x}\text{Fe}_2\text{O}_4$ ($x=0, 0.2, 0.4, 0.6, 0.8$ and 1) were prepared by standard ceramic method. Weighed quantities of AR grade oxides of CuO, ZnO and

Fe_2O_3 were calcinated at 700°C for 24 hr. Powders of these oxides were fired to 950°C for 24 hr and furnace cooled at the rate of 80°C/hr . Pellets of 1 cm diameter and 2 mm thickness were prepared and sintered at a temperature 950°C for 8 hr and furnace cooled at the rate of 80°C/hr . Retaining a series of $\text{Cu}_x\text{Zn}_{1-x}\text{Fe}_2\text{O}_4$ as slow cooled, quenching in air of the samples from 800°C was carried out. The LCR bridge TF 1245 (series) —circuit magnification meter— Marconi Instruments were used for measurements of resistivity and dielectric constant in the range 40 kHz up to 50 MHz. For low frequency measurements Marconi—TF 2700 LCR bridge was used.

3. Result and discussion

Figure 1 shows variation of dielectric constant ϵ' as a function of frequency for the samples of $\text{Cu}_x\text{Zn}_{1-x}\text{Fe}_2\text{O}_4$. It is observed that as the frequency increases the dielectric constant decreases. The dispersion of dielectric constant is similar for all the samples.

Figure 2 shows variation of $\tan \delta$ against the frequency for these samples. Though the nature of the variation for all the samples is similar, the peaks observed change differently lying between 10^5 Hz to 10^6 Hz. The nature of the graph is as expected and agrees well with that reported for other ferrites (Iwanchi 1971; Murthy and Sobhanandri 1975).

Figure 3 shows variation of resistivity as a function of frequency. The resistivity also shows dispersion. Table 1 gives values of ϵ' for $\text{Cu}_x\text{Zn}_{1-x}\text{Fe}_2\text{O}_4$ slow cooled and quenched samples obtained from the experiment.

Figure 1. Dielectric constant variation with log F .

Figure 2. Loss angle, $\tan \delta$ as a function of $\log$ (frequency.)

Figure 3. Resistivity change with $\log F$.

Our value of $\epsilon' = 7$ for CuFe_2O_4 agrees well with its previously reported value (Okamura *et al* 1952).

From table 1, it is seen that on quenching the samples from 800°C the dielectric constants of CuFe_2O_4 and $\text{Cu}_{0.8}\text{Zn}_{0.2}\text{Fe}_2\text{O}_4$ samples increase. The dielectric constants are almost unaffected on quenching the remaining samples. The compositional variation of the dielectric constant at 20 kHz indicates that for the slow cooled ferrite $\text{Cu}_{0.4}\text{Zn}_{0.6}\text{Fe}_2\text{O}_4$ the dielectric constant is large.

Figure 4. Arc plot of ϵ' vs ϵ'' in complex plane.

The cation transfer from *B*-site to *A*-site may be responsible for the changes in dielectric constant on quenching the samples and on addition of Zn in $\text{Cu}_x\text{Zn}_{1-x}\text{Fe}_2\text{O}_4$ system.

Table 1. Dielectric constants of $\text{Cu}_x\text{Zn}_{1-x}\text{Fe}_2\text{O}_4$ slow cooled and quenched samples at various frequencies.

Samples	Dielectric constant ϵ'				
	2' kHz	250 kHz	500 kHz	1 MHz	10 MHz
CuFe_2O_4	7	—	—	—	2.0
CuFe_2O_4 quenched from 800°C	—	—	—	—	3.0
$\text{Cu}_{0.8}\text{Zn}_{0.2}\text{Fe}_2\text{O}_4$	9	1.9	1.8	1.8	1.7
$\text{Cu}_{0.8}\text{Zn}_{0.2}\text{Fe}_2\text{O}_4$ quenched from 800°C	—	3.5	3.4	2.8	2.7
$\text{Cu}_{0.6}\text{Zn}_{0.4}\text{Fe}_2\text{O}_4$	12	3.3	2.9	2.8	2.8
$\text{Cu}_{0.6}\text{Zn}_{0.4}\text{Fe}_2\text{O}_4$ quenched from 800°C	—	2.8	2.7	2.6	1.9
$\text{Cu}_{0.4}\text{Zn}_{0.6}\text{Fe}_2\text{O}_4$	16	2.6	2.5	2.3	2.3
$\text{Cu}_{0.4}\text{Zn}_{0.6}\text{Fe}_2\text{O}_4$ quenched from 800°C	—	2.4	2.4	2.3	2.1
$\text{Cu}_{0.2}\text{Zn}_{0.8}\text{Fe}_2\text{O}_4$	14	2.6	2.6	2.4	2.4
$\text{Cu}_{0.2}\text{Zn}_{0.8}\text{Fe}_2\text{O}_4$ quenched from 800°C	—	2.5	2.5	2.4	2.1
ZnFe_2O_4	13	2.6	2.4	2.4	1.98
ZnFe_2O_4 quenched from 800°C	—	2.1	1.9	1.9	1.60

Figure 4 is a graph of ϵ' vs ϵ'' in complex plane for the sample $\text{Cu}_{0.6}\text{Zn}_{0.4}\text{Fe}_2\text{O}_4$. Other samples behave in a similar fashion hence their plots are not reported. From this plot it is clear that there is distribution of relaxation time suggesting a distribution of critical resistivity as well. Other ferrites are also reported to have shown similar behaviour (Iwauchi 1971). The nature of the plot suggests that heterogeneities producing interfacial polarisation exist in the sample.

Koops (1951) has explained the dispersion phenomenologically by considering the conducting regions and insulating layers as made up of parallel capacitors and resistor circuits giving rise to an equivalent parallel resistor capacitor

circuit *i. e.* the interrelationship between the dielectric and the conducting properties of the regions change with frequency and thus effectively constitute polarisation.

Figures 1, 2 and 3 exhibit dispersion characteristics of ϵ' , ρ and $\tan \delta$ respectively which are in general agreement with Koops model showing relaxation due to interfacial polarisation. However, the change in the characteristics with composition indicates that this simplistic model will have to take into consideration the details of the conducting and non-conducting regions. There is a possibility that the regions themselves may be inhomogeneous within as multidomain grains or other domain geometries are possible. These considerations appear to be essential especially for the studies of the present type when composition tends to change the interrelationship between the so-called elementary capacitor resistor circuits giving rise to the change in the trend in the relative properties of the composition in the frequency regions separated by the relaxation frequency.

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