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Effect of gamma irradiation on ac conductivity, dielectric and magnetic properties of $CdFe_2O_4$ ferrite

E Nagaraja, AS Jagadisha, HS Jayanna

Department of Physics, Kuvempu University, Shankaraghatta, Karnataka, India

Abstract

$CdFe_2O_4$ ferrite is prepared by ceramic technique. The prepared samples are irradiated using high energy gamma radiation of ^{60}Co source with a dose rate 6.972 kGy per hour to different doses of 300 kGy and 500 kGy. The XRD spectra are obtained for the irradiated samples and compared with that of the pristine sample to study the changes in the structure. The obtained results showed that the crystallite size decreases and lattice strain increases with the increase of radiation dose. Variation of ac conductivity, dielectric constant and dielectric loss ε'' with frequency and radiation dose at room temperature are studied for the $CdFe_2O_4$ ferrite. Room temperature M-H curves are traced for the un-irradiated and irradiated samples. It is observed that the electrical properties, ac conductivity, dielectric constant ε' and dielectric loss ε'' and magnetic properties, saturation magnetization M_s and remanence M_r are all increased after gamma irradiation.

Keywords: ac conductivity, dielectric properties, magnetic properties, gamma irradiation

1. Introduction

Ferrites are magnetic oxides which have been thoroughly studied during the last decades, due to their technological wide importance in the field of communication and electronic devices. They are still a matter of interest because of promising materials for magnetic recording media, micro wave devices, and miniature of electro-optic modulators, transformer cores, ferrite insulators, memory core industry [18, 19, 20]. Cadmium ferrite ($CdFe_2O_4$) has a normal spinel structure AB_2O_4. Eight tetrahedral (A-sites) sites contain divalent and sixteen octahedral (B-sites) sites contain trivalent metal ions. Cadmium is anti-ferromagnetic and show n-type conduction. The magnetic properties of a spinel ferrite are strongly dependent on the distribution of different cations among tetrahedral (A) and octahedral (B) sites in the crystal lattice [20].

Irradiation process produces crystallographic defects and changes in properties of ferrites. Various kinds of radiations such as fast neutrons, energetic ions and γ-rays are used to study the effect of radiation on the properties of ferrites with different compositions [21-28]. This paper tries to present the effect of gamma radiation on ac conductivity, dielectric constant, dielectric loss and magnetic properties of $CdFe_2O_4$ ferrite.

2. Experimental

The $CdFe_2O_4$ ferrite is prepared by the ceramic method. The formation of spinel phase and crystal structure was confirmed by x-ray diffraction. The samples are irradiated with the energetic gamma radiation with dose rate of 6.972 kGy per hour to different doses of 300 kGy and 500 kGy. Micro structural analysis of the prepared samples is carried out by Scanning Electron Microscopy (SEM) both before and after irradiation and EDAX is used to determine the quantities of cadmium and Iron in the prepared samples.

Parallel plate capacitance (Cp), and $tan\delta$ are measured for the pallet samples using LCR bridge meter model PSM1735 (N4L make) operating in the frequency range of 1kHz-1MHz. The dielectric constant (ε') and dielectric loss (ε'') are calculated using the formulae,

$$\varepsilon' = \frac{C_p d}{\varepsilon_0 A}$$

$$\varepsilon'' = tan\delta \ \varepsilon'$$

Where, d the thickness of the pallets, A the cross-sectional area of the flat surfaces of the sample and ε_0 the permittivity of free space $(\varepsilon_0 = 8.85 \times 10^{-12}\ F/m)$. Further the ac conductivity is calculated using the formula.

$$\sigma_{ac} = (\varepsilon' \varepsilon_0 \ \omega \ tan\ \delta)$$

Where, ω is the angular frequency

M-H curves are obtained at room temperature by using Vibrating Sample Magnetometer (VSM, max field 1T).

3. Results and Discussions

3.1 AC Conductivity

Figure (1) shows the variation of ac conductivity (σ_{ac}) with frequency at room temperature, of the un-irradiated and irradiated samples (dose: 300 kGy and 500 kGy). It is noted that, σ_{ac} increases with frequency and radiation dose.

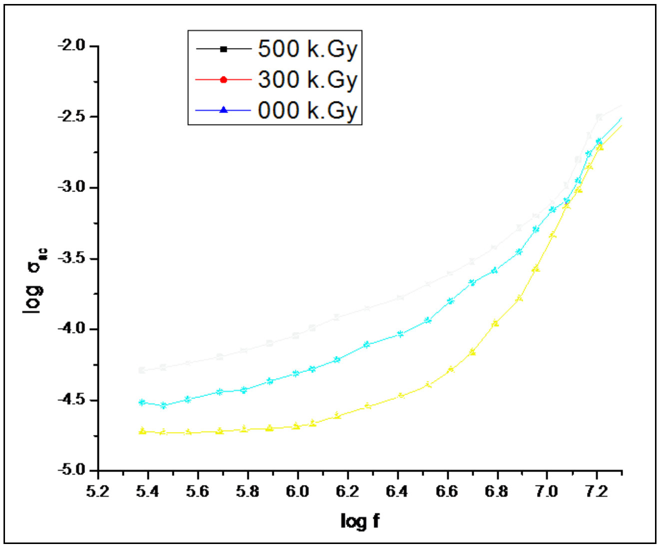

Fig 1: Variation of ac conductivity with frequency and radiation dose at room temperature for the $CdFe_2O_4$ ferrite.

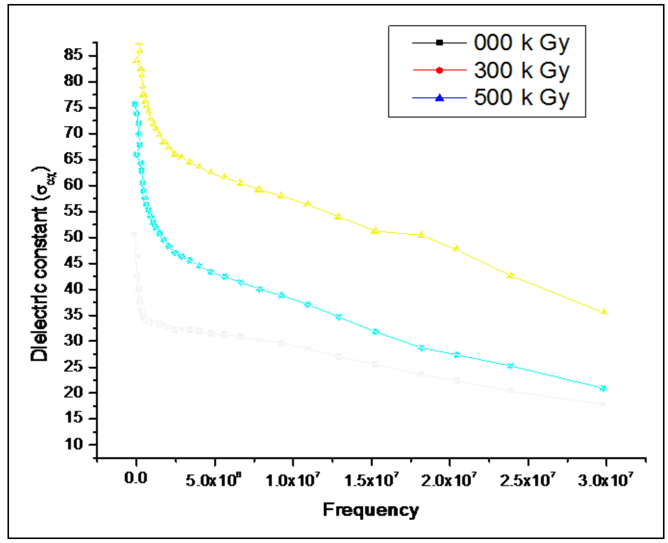

Fig 2: Variation of dielectric constant ε' with frequency and radiation dose at room temperature for the $CdFe_2O_4$ ferrite.

The electrical transport phenomenon in the ferrites is explained on the basis of hopping model of the electrons. In this model the electron jump between Fe^{2+} and Fe^{3+} ions. Increase of frequency increases the electron hopping rate and hence increases the conductivity [1, 2, 3]. The frequency dependence of the conductivity can be explained using Koops's model [4]. According to this model, the polycrystalline ferrite is considered to be composed of two layers, grains and grain boundaries. According to Koops's assumption, the grains have high conductivity and grain boundaries have low conductivity. The high conductivity at higher frequencies is mainly due to grains, which have low resistivity. On the other hand the low conductivity at lower frequencies is mainly due to grain boundaries, which have high resistivity.

The increase of σ_{ac} for the irradiated samples can be attributed to the increase of Fe^{2+}/Fe^{3+} ratio on the octahedral sites. This increase in σ_{ac} of ferrites after γ-irradiation is reported by different authors [5, 6].

3.2 Dielectric constant

Figure 2 shows the variation of dielectric constant ε' with frequency at room temperature for the un-irradiated and γ-irradiated samples. It can be seen that, ε' initially decreases rapidly and then gradually decreases with frequency. It is also noted that ε' increases with radiation dose.

The decrease of dielectric constant with increase in frequency, observed in the case of several mixed ferrites, is a normal dielectric behavior [7, 8, 9]. This can be explained on the basis of space charge polarization model of Maxwell [10] Wagner [11], and the Koop's theory [4]. It is assumed that the polycrystalline ferrite is composed of wide conducting grains separated by the thin poor conducting grain boundaries. The electrons reach the grain boundary by hopping mechanism and if the resistance of the grain boundary is high enough, electrons pile up at the grain boundaries and produce polarization. However, as the frequency of the applied field is increased beyond a certain value, the electrons cannot follow the alternating field. This decreases the possibility of further electrons reaching the grain boundary and as a result the polarization decrease.

The slight increase in ε' with the radiation dose can be explained by considering the following gamma interaction.

$$Fe^{3+} + \gamma \rightarrow Fe^{2+} + e^{-}$$

This interaction creates Fe^{+2} ions at the octahedral sites and increases the ratio Fe^{2+}/Fe^{3+} at these sites (B sites) [1, 5, 12]. This leads to local displacement of charges, which is responsible for polarization and a consequent contribution for the rise of ε'.

3.3 Dielectric loss

Figure 3 shows the variation of dielectric loss ε" with frequency at room temperature for the un-irradiated and irradiated samples. It can be seen that, ε" decreases with frequency. It can also be noted that ε" increases with radiation dose.

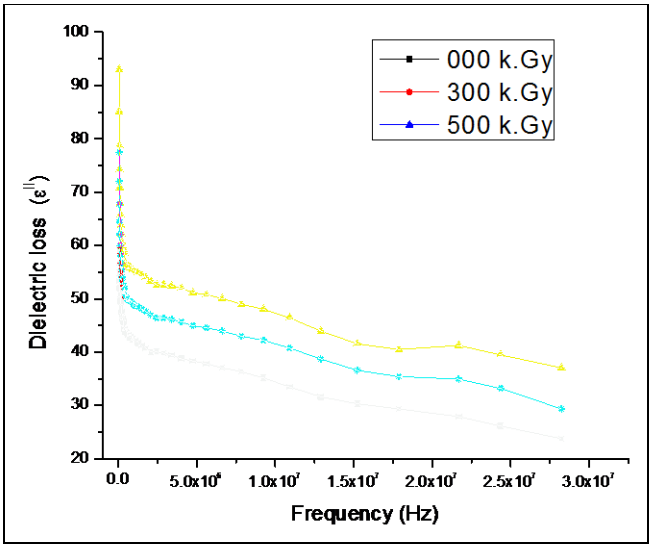

Fig 3: Variation of dielectric loss ε" with frequency and radiation dose at room temperature for the $CdFe_2O_4$ ferrite.

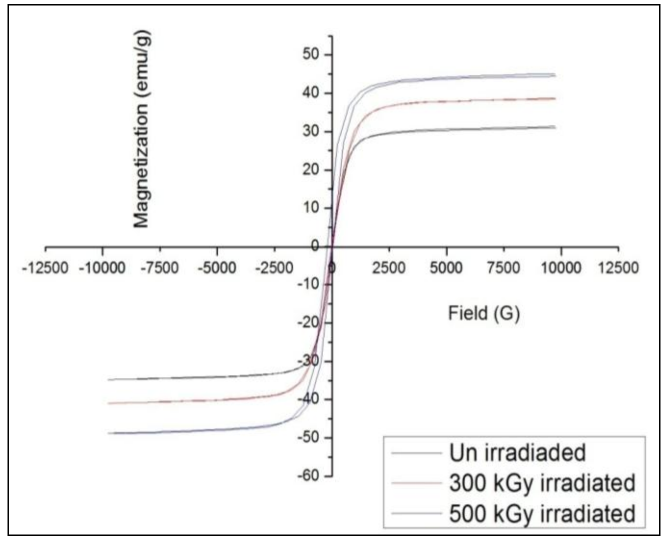

Fig 4: M-H curves at room temperature for the un-irradiated and irradiated $CdFe_2O_4$ ferrite.

Initially the dielectric loss decreases drastically with increasing frequency and then shows slow variation with frequency. When the frequency of the applied ac electric field is much smaller than hopping frequency of electrons between Fe^{2+} and Fe^{3+} ions at equivalent octahedral sites, the electrons follow the field and hence the loss is maximum. At higher frequencies of the applied electric field, the hopping frequency of the electron exchange between Fe^{2+} and Fe^{3+} ions cannot follow the applied field frequency and the loss is minimum. The variation of dielectric loss with frequency is similar to that of dielectric constant [6, 13].

The increase of ε" after γ -irradiation is attributed to the increase of the conductivity due to irradiation process. This increases the eddy current loss and then ε" increases which is in good agreement with the following relation [3, 6].

$$\sigma_{ac} = \varepsilon'' \varepsilon_0 \omega$$

3.4 Magnetic Properties

Figure 4 shows the hysteresis curves (M-H curves) at room temperature for all the investigated samples. Saturation magnetizations (M_s) and remanence (M_r) for the un-irradiated and irradiated samples are given in Table 1. It is observed that, M_s and M_r are increased for all the investigated samples with gamma radiation dose,. Similar results are reported for other ferrites [27, 28, 29].

The areas of the hysteresis loops are small, loops are thin and narrow showing the soft ferrite nature. The un-irradiated and irradiated samples show similar magnetization with an enhancement in the magnetic parameters after irradiation. These changes may be attributed to the increase in the Fe^{2+}/Fe^{3+} ratio after irradiation process. This causes the increase in net magnetic moment leading to the rise in the saturation magnetization M_s [17].

Table 1: Magnetic parameters at room temperature for the un-irradiated and irradiated $CdFe_2O_4$ ferrite.

Radiation dose kGy	Magnetization (M_s) emu/g	Retentivity (M_r) emu/g
0	1.9743	19.690×10^{-3}
300	2.2670	39.530×10^{-3}
500	2.6686	88.460×10^{-3}

4. Conclusions

Dispersion curves of the dielectric constant ε' and dielectric loss ε" with frequency are found to be decreased with frequency while ac conductivity increases with frequency. Saturation magnetization M_s and remanence M_r are increased with radiation dose. The increase of the ac conductivity, dielectric constant, dielectric loss and magnetic parameters after γ-irradiation is related to the increase of the ratio Fe^{2+}/Fe^{3+}.

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