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Synthesis, Characterization and Electrical Properties of $ZnFe_2O_4$ Nanoparticles

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ABSTRACT

Zinc ferrite ($ZnFe_2O_4$) nanoparticles were prepared by combustion method. The FT-IR, XRD and SEM with EDS were used to characterize the prepared sample. The characterization results confirm the successful synthesis of $ZnFe_2O_4$ nanoparticles with the particle size range of 24 – 30 nm. The temperature dependent DC conductivity of the sample has been studied in the temperature range 30-175 °C and AC conductivity was investigated between the frequencies of 10 Hz and 10 MHz. DC conductivity of the sample was increased while increasing temperature and AC conductivity was increased as the frequency increased.

1. Introduction

Magnetic nanoparticles already gained significance in a variety of fields, which include ferrofluids, magnetic separations, magnetic drug delivery, magnetic data storage systems, magnetic resonance imaging (MRI) and so on [1-8]. Magnetic nanoparticles are promising catalysts because they can be separated from the response medium by adding a magnetic attractive field from the outside. In comparison to filtration or centrifugation, magnetic partition is a magnificent choice because it prevents catalyst failure and improves reusability, making the catalyst cost-effective and suitable for advanced applications [9-11]. A significant class of magnetic metal oxide materials is cubic spinel ferrites. Zinc ferrite nanoparticles being invaluable among ferrite materials because of their specific magnetic, magneto-resistive, magneto-optical, mechanical, thermal, and electric characteristics including ferromagnetism, outstanding creep and resistance to radiation damage tolerance, higher thermal conductivity higher electric resistivity, and configurable saturation magnetization, the thermal expansion coefficients are moderate, the energy transfer performance is high, and in ferromagnetic resonance the line width is narrow [12-16] and also zinc ferrite is noteworthy because of its possible applications in data storage media, adsorption, sensors, and other appealing technologies. It has low saturation magnetization and excellent photo-induced catalytic reactant properties, high electric resistivity and low eddy current lost and uniform and reproducible qualities [17-20].

2. Experimental Methods

2.1 Materials and Methods

All of the chemicals were AR grade and they were used exactly as they were received. Throughout the solution preparation and experiment, double distilled water was used.

2.2 Synthesis of Zinc Ferrite Nanoparticles

A known quantity of zinc salt and iron salt were mixed thoroughly and ground well with polyvinyl alcohol in a pestle and mortar in a 1:5 ratio to produce zinc ferrite ($ZnFe_2O_4$) nanoparticles. The reaction product was transferred to a crucible, which was initially burned in an electrical oven to complete the fume evolution. The resulting residue was continually heated at temperature 500 – 600 °C and the reaction took 30 minutes for the complete combustion, yielding brown colored crystalline $ZnFe_2O_4$. Carbon impurities in the ferrite sample are eliminated by cooling to room temperature and then treating with acetone. The carbon that passes into the acetone was decanted and the acetone being evaporated. The same procedure was clearly explained in our earlier work [21]. The chemical reaction is as shown below.

$$\underset{\text{(Zinc nitrate)}}{2Zn(NO_3)_2} \longrightarrow \underset{\text{(Zinc oxide)}}{\mathbf{2ZnO}} + \underset{\text{(Nitrous oxide)}}{4NO_2} + O_2$$

$$\underset{\text{(Ferrous nitrate)}}{4Fe(NO_3)_2} \longrightarrow \underset{\text{(Ferric oxide)}}{\mathbf{2Fe_2O_3}} + \underset{\text{(Nitrous oxide)}}{8NO_2} + O_2$$

$$\underset{\text{(Zinc nitrate)}}{ZnO} + \underset{\text{(Ferric oxide)}}{Fe_2O_3} \xrightarrow{500-600\,^{\circ}C} \underset{\text{(Zinc Ferrite)}}{\mathbf{ZnFe_2O_4}}$$

2.3 Instrumentation Techniques

In this study FTIR spectra of the considerable number of tests are recorded on ThermoNicolet, Avatar 370 IR spectrometer in KBr medium at ambient room temperature. Powders are combined with KBr in a 1:25 weight ratio to ensure uniform dispersion in KBr pellets for capturing FT-IR spectra. The morphology of the sample was observed by using Joel model JSM-6390 LV scanning electron microscope (SEM). A two probe setup is used for measuring DC conductivity and AC conductivity measurements of the sample at room temperature was performed using LCR meter Newton Model PSM-1735 NumetriQ with a Kelvin fixture between the frequencies of 10 Hz and 10 MHz.

3. Results and Discussion

3.1 FT-IR and XRD Analysis

The FT-IR spectrum of $ZnFe_2O_4$ nanoparticles is shown in Fig. 1. Two absorption peaks below 600 cm^{-1} can be seen in Fig. 1, which is a typical characteristic of all spinel ferrites. The vital peaks observed in $ZnFe_2O_4$ are 550 cm^{-1} and 453 cm^{-1} are due to the presence of M–M bond and M–O stretching frequencies respectively [22]. However, organic material traces were found at 1603 cm^{-1} and 1115 cm^{-1}, which have been associated to C=O and CO_2 stretching vibrations, respectively [23]. From our earlier article [21], XRD analysis confirms the sizes of $ZnFe_2O_4$ nanoparticles found over the range 24 – 30 nm and the prominent peaks corresponds respective planes were coordinate with the polycrystalline nature type of $ZnFe_2O_4$ JCPDS No. 82-1042.

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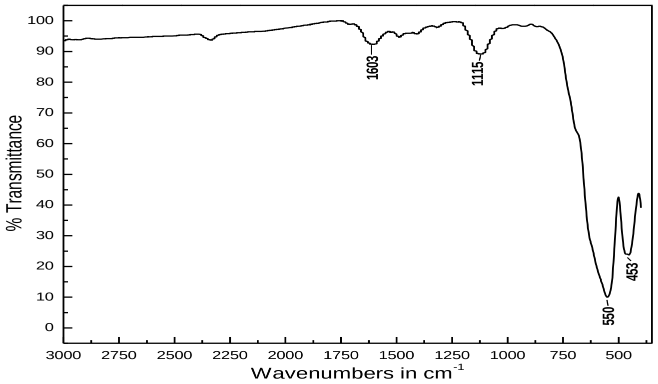

Fig 1 FT-IR spectra of $ZnFe_2O_4$ nanoparticles

3.2 SEM and EDS Analysis

Fig. 2 shows the scanning electron micrograph of $ZnFe_2O_4$ nanoparticles. The observation from the SEM images displays agglomerates of $ZnFe_2O_4$ nanoparticles due to the moisture content in the sample and they are highly branched as well as porous in nature.

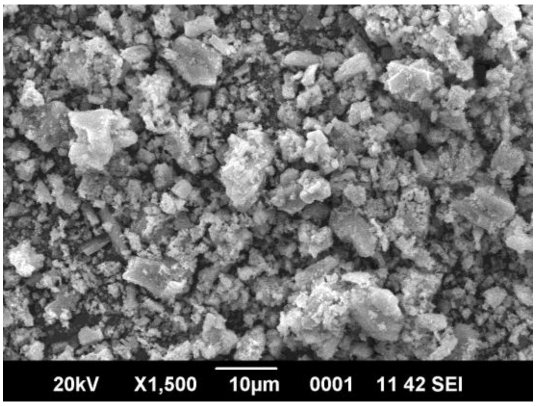

Fig. 2 SEM image of $ZnFe_2O_4$ nanoparticles

The EDS analysis was used to determine the identity of metals as well as impurities in the synthesized $ZnFe_2O_4$ nanoparticles. The EDS spectrum of synthesized $ZnFe_2O_4$ nanoparticles displayed in Fig. 3 reveals only the presence of Fe, Zn, and O with C being an impurity signal. Fe and Zn element indicates the presence of those elements successfully synthesized $ZnFe_2O_4$ nanoparticles. The presence of O and C is due to the presence of some organic additives from the environment, which is also confirmed by FT-IR.

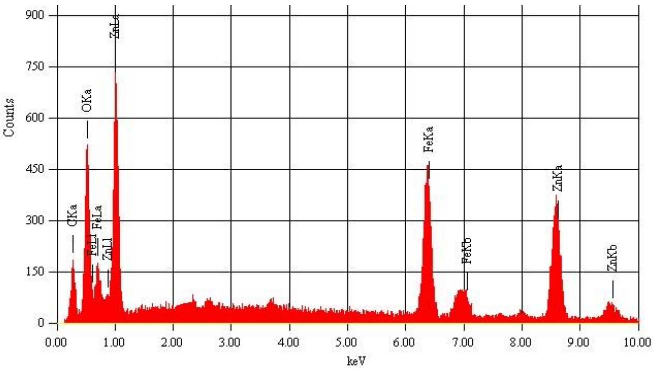

Fig. 3 EDS spectrum of $ZnFe_2O_4$ nanoparticles

3.3 DC Conductivity

The direct current conductivity 'σ_{DC}' is computed for $ZnFe_2O_4$ nanoparticles by measuring current flowing through the sample and its dimensions using the equation, $\sigma = \left(\frac{d}{AV}\right) I$, Scm^{-1}, where d (cm) is the sample thickness, A (cm^2) is its area, V (volt) is the potential across the material which is kept constant and I (ampere) the current flowing across the material. The σ_{DC} for $ZnFe_2O_4$ nanoparticles increases with increase in temperature. The room temperature σ_{DC} of $ZnFe_2O_4$ nanoparticles was found to be 1.02×10^{-9} S cm^{-1} as shown in Fig. 4. The σ_{DC} of $ZnFe_2O_4$ nanoparticles was observed to increase with increasing temperature, exhibiting characteristics of a semiconducting material.

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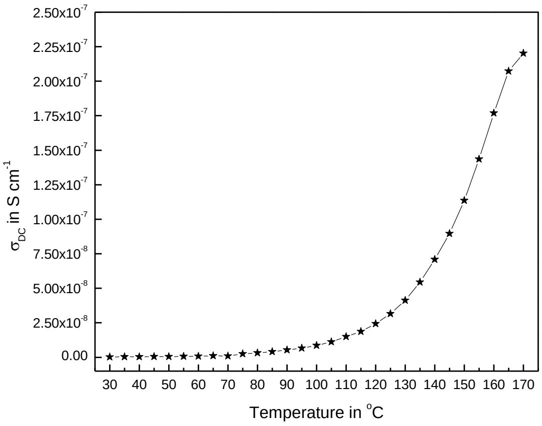

Fig. 4 Variation of σ_{DC} versus temperature for $ZnFe_2O_4$ nanoparticles

3.4 AC Conductivity

The material's AC conductivity (σ_{AC}) is frequency dependent. The dielectric parameters were used to measure the AC of $ZnFe_2O_4$ nanoparticles. Fig. 5 depicts the dependency of σ_{AC} on $ZnFe_2O_4$ nanoparticles and the frequency of the applied AC field. It implies that σ_{AC} is highly frequency dependent. The graph clearly shows that as frequency increases, the σ_{AC} of $ZnFe_2O_4$ nanoparticles is also get increased. The hopping of charge carriers between Fe^{2+}–Fe^{3+} ions in octahedral sites will describe the conduction process in ferrites [24]. The σ_{AC} of a system is determined by the material's dielectric properties and capacitance.

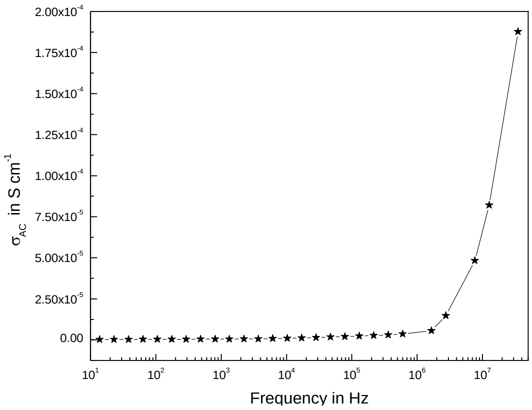

Fig. 5 Frequency dependence of σ_{AC} of $ZnFe_2O_4$ nanoparticles

4. Conclusion

$ZnFe_2O_4$ nanoparticles were synthesized successfully by combustion method. The FT-IR analysis validate the formation of $ZnFe_2O_4$ nanoparticles supported by EDS spectrum. The results of the DC conductivity of $ZnFe_2O_4$ nanoparticles was observed as increased with increasing temperature, exhibiting characteristics of a semiconducting material and AC conductivity was increased with increasing frequency.

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