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Enhanced microwave absorption properties in cobalt–zinc ferrite based nanocomposites

A. Poorbafrani*, E. Kiani

Electroceram Research Center, Malek Ashtar University of Technology, Shahin Shahr 83145-115, Iran

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ABSTRACT

In an attempt to find a solution to the problem of the traditional spinel ferrite used as the microwave absorber, the $Co_{0.6}Zn_{0.4}Fe_2O_4$–Paraffin nanocomposites were investigated. Cobalt–zinc ferrite powders, synthesized through PVA sol–gel method, were combined with differing concentrations of Paraffin wax. The nanocomposite samples were characterized employing various experimental techniques including X-Ray Diffraction (XRD), Field Emission Scanning Electron Microscopy (FESEM), Alternating Gradient Force Magnetometer (AGFM), and Vector Network Analyzer (VNA). The saturation magnetization and coercivity were enhanced utilizing appropriate stoichiometry, coordinate agent, and sintering temperature required for the preparation of cobalt–zinc ferrite. The complex permittivity and permeability spectra, and Reflection Loss (*RL*) of $Co_{0.6}Zn_{0.4}Fe_2O_4$–Paraffin nanocomposites were measured in the frequency range of 1–18 GHz. The microwave absorption properties of nanocomposites indicated that the absorbing composite containing 20 wt% of paraffin manifests the strongest microwave attenuation ability. The composite exhibited the reflection loss less than –10 dB in the whole *C*-band and 30% of the *X*-band frequencies.

1. Introduction

In step with the development of GHz microwave communication, radar detection and other industrial applications, electromagnetic wave absorbing materials in the GHz range have attracted much attention in recent years. These absorbing materials can be manufactured by a number of magnetic and dielectric materials in powder forms, loaded in various kinds of polymeric binders. Various electromagnetic wave absorbing materials can be designed by using the dispersion characteristic of the complex permittivity and permeability [1–6]. Microwave absorption properties are highly dependent on processing parameters and chemical composition. These factors can greatly influence the crystal size, magnetic properties, complex magnetic permeability (μ_r) and complex permittivity (ε_r) [7–13].

Cobalt–zinc ferrites are well-known magnetic ceramics used in electrical equipment and microwave devices. When used in high frequency inductors or transformers, the core loss of ferrite is minimal because of their high electrical resistivity and magnetic softness [14,15]. Soft magnet cobalt–zinc ferrite with good mechanical hardness and chemical stability, has a large saturation magnetization and high Snoek's limit, resulting in highly complex permeability values at a wide frequency range. The above factor makes cobalt-zinc ferrite highly useful as a thin absorber working at a high frequency band [16–18].

In the present work, an attempt was made to study microwave absorption properties of Cobalt Zinc Ferrite (CZF) nanocomposites. Ferrite phase was prepared, through sol–gel method. The process was carried out under appropriate stoichiometry, which enhanced magnetic properties of the phase. The magnetization curve of Co–Zn ferrite at room temperature showed high saturation magnetization of the magnetic phase. The formation of the $Co_{0.6}Zn_{0.4}Fe_2O_4$ phase, crystalline properties and morphology of the ferrite have been discussed through XRD analysis and FESEM images. In order to study the electromagnetic parameters and absorbing properties of the resulting powder, the $Co_{0.6}Zn_{0.4}Fe_2O_4$–paraffin wax composite was prepared. Paraffin wax is an insulating and non-magnetic material. In addition, considering the zero value of the imaginary part of the complex permittivity and permeability, paraffin wax is transparent for electromagnetic wave. Thus, in the present research, paraffin wax was chosen as a matrix and binder to prepare toroidally shaped samples, which were subsequently used in measuring the complex permittivity and complex permeability of Co–Zn ferrite based nanocomposites.

2. Experimental procedures

Synthesis of the CZF nanoparticles was based on our previous study [19], in which PVA solution was prepared by dissolving PVA

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* Corresponding author.
E-mail address: a.poorbafrani@gmail.com (A. Poorbafrani).

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powders in deionized water (3% w/v) at temperatures between 70 and 80 °C and then the sols were prepared by dissolving ferric nitrate, cobalt nitrate and zinc nitrate in deionized water in stoichiometric ratio of 2:0.6:0.4. Being stirred constantly for 4 h, the sols were added drop wise to PVA solution. The subsequent mixture was then heated to 80 °C and subjected to constant stirring till a gel was obtained. The gel heated to 90 °C for 10 h to evaporate the water content. After that, the temperature was increased to 140 °C for 2 h until the gel was dried. The precursor was then sintered at 800 °C for 4 h.

In order to prepare CZF nanocomposites, CZF powders were mixed with Paraffin wax at a concentration of CZF/paraffin by the weight ratios of 50/50, 60/40, 70/30 and 80/20. Subsequently, the composites were pressed into a toroidal shape.

The X-ray diffraction (XRD) pattern of the sample was taken on Philips XPERT X-ray Diffractometer with Cu *Kα* radiation ($\lambda = 1.5406$ A°) in the range of 2*θ* (25° < 2*θ* < 85°). The morphology of the sample was characterized using a Field Emission Scanning Electron Microscope (Hitachi S4160). Magnetic measurement was carried out at room temperature using an Alternating Gradient Force Magnetometer (AGFM: Meghnatis Daghigh Kavir Co., Iran) with a maximum magnetic field of 12 kOe. The real and imaginary parts of permittivity and permeability of nanocomposites were measured by a Vector Network Analyzer in the frequency range of 1–18 GHz. In order to measure the above parameters, the composites were pressed into toroidally shaped samples with different thicknesses having an inner diameter of 3.04 mm, and an outer diameter of 7.0 mm. The reflection loss (*RL*) of each composite was calculated from the complex relative permittivity and permeability at given frequencies and absorber thicknesses.

3. Results and discussion

Fig. 1 shows the XRD pattern of the $Co_{0.6}Zn_{0.4}Fe_2O_4$ powder synthesized through PVA sol–gel method. The prominent peaks were observed at 2*θ* values of 30°, 35.5°, 37°, 43°, 53.5°, 57°, 62.5° and at 74° were assigned to (220), (311), (222), (400), (422), (511), (440) and (533) planes, in the order mentioned. All these peaks confirm the cubic spinel type lattice of $Co_{0.6}Zn_{0.4}Fe_2O_4$ matching well with the standard XRD pattern (JCPDS card no. 22-1086). No additional peaks were observed in this XRD pattern, suggesting that no other phases besides cobalt–zinc ferrite structure were detected in the sample. The average crystallite diameter of the CZF nanoparticles was determined from the major diffraction peak (311) and the calculated value was found to be about 30 nm.

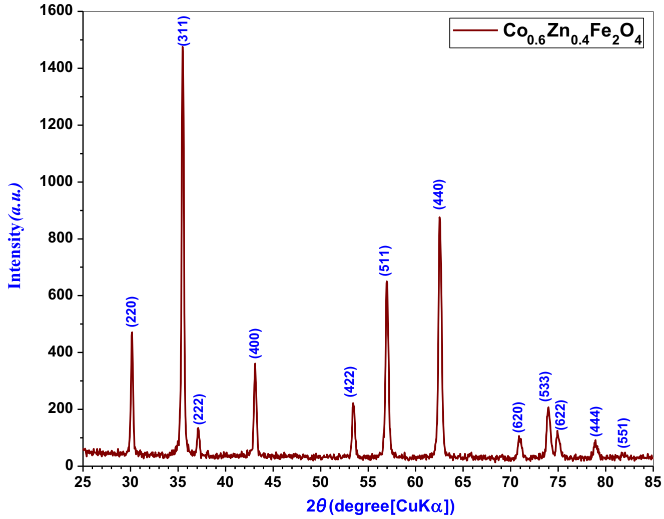

Fig. 1. XRD pattern of cobalt zinc ferrite (CZF) nanoparticles.

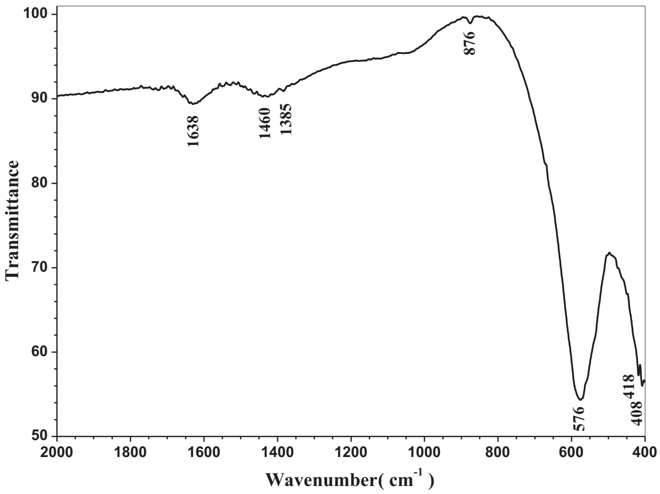

Fig. 2. FTIR spectrum of cobalt zinc ferrite nanoparticles.

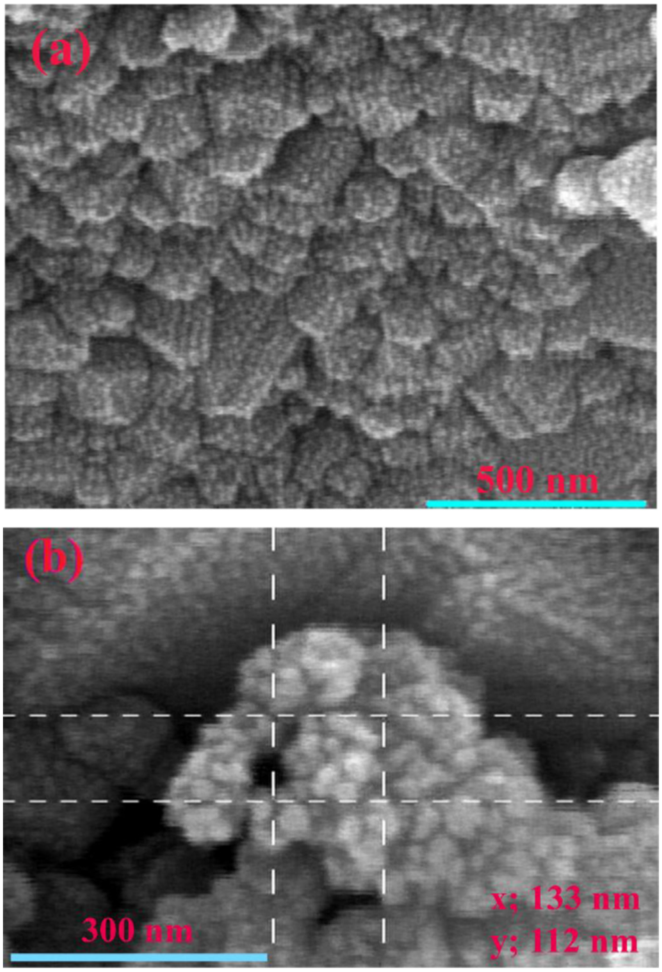

Fig. 3. FESEM Images of cobalt zinc ferrite nanoparticles at different length scales.

Fig. 2 shows the FTIR spectrum of the cobalt–zinc ferrite nanoparticles. The peaks at 408, 418 and 576 cm^{-1} are assigned to the characteristic Metal Oxide (M-O) stretching vibrations of cobalt–zinc ferrite which were located in the region between 400 cm^{-1} and 600 cm^{-1} [20]. In ferrites, according to the