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Spectroscopy of peaks at microwave range for nanostructure $SrFe_{12}O_{19}$ and $NiFe_2O_4$ ferrite particles

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ABSTRACT

In this paper, ($SrFe_{12}O_{19}$ and $NiFe_2O_4$) nanostructure ferrite particles were synthesized via the co-precipitation of chloride salts utilizing the sodium hydroxide solution. The resulting precursors were heat-treated at 1100 °C for 4 h. After cooling in the furnace, the ferrite powders were pressed at 0.1 MPa and then sintered at 1200 °C for 4 h. The spectroscopy and characterization of peaks at the microwave range (X-band) for the nanostructure ferrite particles were investigated by the ferromagnetic resonance/transmit-line theories and Reflection Loss (RL) plots. The extracted data from these theoretical and experimental results showed that the natural ferromagnetic resonance can be lead to the narrow peaks and the width of the peaks can be related to the periodic effects. Two kinds of peaks were seen for $NiFe_2O_4$ at X-band (8–12 GHz); the narrow peak at (9.8 GHz) was remaining unchanged and consistent while the wide one was shifted from 11 GHz to 8.5 GHz by decreasing the thickness of the samples. These phenomena were also happened for $SrFe_{12}O_{19}$ samples. The natural resonance was not happened due to the hard magnetic properties of these nano structure particles.

1. Introduction

Spectroscopy is the study of the interaction takes place between a matter and radiated energy. Historically, spectroscopy originated through the study of visible light dispersed according to its wavelength, by a prism. Later the concept was expanded greatly to comprise any interaction with radiated energy as a function of its wavelength or frequency. Types of spectroscopy can be distinguished by the type of the radiated energy involved in the interaction. In many applications, the spectrum is determined by measuring the changes in the intensity or frequency of this energy. Various types of radiated energy are microwave, terahertz, infrared, near infrared, visible and ultraviolet, x-ray and gamma [1–4]. Among them, the spectroscopy of microwave range for obtaining the physical properties of materials have not been investigated vastly to date. Hence, the microwave range spectroscopy was focused in this study to acquire some dominant information which in turn shed light on the physical properties of the materials.

In some previous works about magnetic materials, ferrites have been investigated vastly [5–8]. So, in this work, these materials were considered suitable choices for studying the characteristics of the interaction and spectroscopy of their peaks at microwave range. Ferrites are classified into three groups according to their crystalline structures (hexaferrite, spinel and garnet). Hexaferrites are classified into six classes according to their compositions and crystalline structures. They are M, W, X, Y, Z and U type hexaferrites [9,10]. The M-type strontium hexaferrite ($SrFe_{12}O_{19}$), with a hexagonal structure and hard magnetic properties, has also been the subject of continuous interest as an electro-magnetic (EM) material for several decades due to its applicability as a dielectric or a magnetic filler in various electromagnetic attenuations [11]. On the other hand, nickel ferrite ($NiFe_2O_4$), which has a cubic spinel structure, is a kind of soft magnetic material and has been studied as a magnetic material too [12].

The present investigation deals with the synthesis of $SrFe_{12}O_{19}$ and $NiFe_2O_4$ nanostructure particles of by the co-precipitation method and analyzing the effects of the ferrite kind and the samples thickness on the electromagnetic properties. The microwave absorption properties for the nanostructure particles were studied by Reflection Loss plots via Network Analyzer measurement, ferromagnetic resonance and transmit-line theories.

2. Experimental procedure

In the present investigation, analytical-grade ferric chloride ($FeCl_3$, $6H_2O$), strontium chloride ($SrCl_2$, $6H_2O$), nickel chloride ($NiCl_2$) and NaOH were used for the synthesis of ($SrFe_{12}O_{19}$ and $NiFe_2O_4$) nanostructure particles by co-precipitation. Stoichiometric amounts

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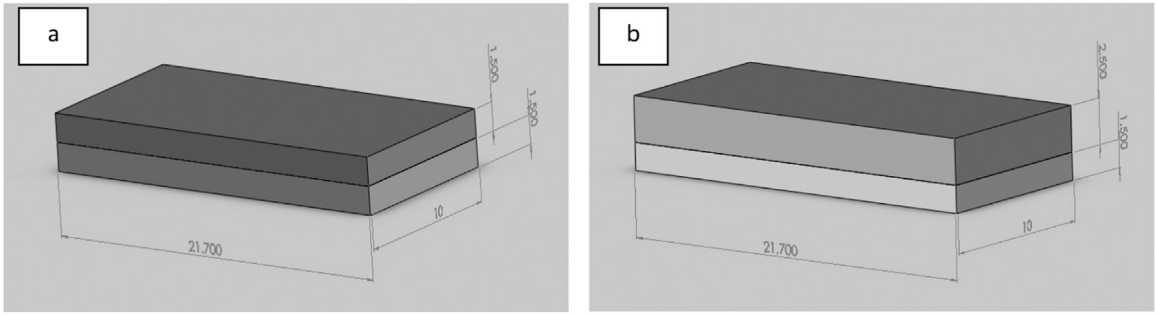

Fig. 1. Schematic views of the prepared samples for reflection loss measurements (a) d=1.5 (b) d=2.5.

of strontium, ferric and nickel chlorides dissolved completely in ultrapure water to make an aqueous solution. The brownish-colored ferrite particles were precipitated from this mixture by gradually adding the sodium hydroxide (NaOH) to the solution at room temperature up to (pH=12). The aqueous suspension was stirred gently for 15 min to achieve good homogeneity. The resulting precipitates were filtered off, washed with water, and dried at 100 °C in an oven overnight. The as-synthesized particles were heat-treated at 1100 °C for 4 h with 10 °C/min heating rate. After the ferrite powders were cooled in the furnace, they were pressed gently at 0.1 MPa and sintered at 1200 °C for 4 h. The bulk samples were crushed in order to prepare the sintered nano structure ferrites powders.

The phase identification of the annealed samples was carried out by x-ray diffraction (XRD) using a (Siemens, D5000) diffractometer with Cu k_α radiation. The morphological study was conducted by scanning electron microscopy (SEM, Hitachi S4160). Magnetic measurements were made at room temperature in the applied field range of −10 kOe to 10 kOe by means of a magnetometer (Magnet-Physik, C-300). In order to prepare samples and study absorption properties, all the samples were mixed with 27 $_{wt.}$% epoxy resin and 3% hardener. The resulting ferrite particulate reinforced polymer matrix composite was cast into a rectangular pellet (21.7×10 mm^2) with thicknesses of 2.5 and 1.5 mm and then cured at room temperature for 24 h. The cured composite was polished and mounted on an aluminum foil (to obtain a single-layer metal-backed absorber) to exactly fit into the measuring waveguide. The schematic view of the prepared samples is illustrated in Fig. 1. The Reflection Loss measurements were carried out using a Network Analyzer (ST8410-C) in the X-band from 8 GHz to 12 GHz at room temperature.

3. Results and discussion

3.1. XRD and SEM results

The indexed XRD pattern of the nanostructure ferrite particles (SrFe12O19 and NiFe2O4) after sintering was shown in Fig. 2. The X-ray diffraction patterns for $SrFe_{12}O_{19}$ and $NiFe_2O_4$ powders indicate the existence of single hexagonal and cubic phases. The contributions related to the crystal structure were found to be in good agreement with those obtained by a JCPDS card ($2\theta = 34.198°$; no. 01-072-0739) for $SrFe_{12}O_{19}$ and a JCPDS card ($2\theta = 35.452°$; 00-044-1485) for $NiFe_2O_4$. The crystallite size of the $SrFe_{12}O_{19}$ and $NiFe_2O_4$ powders (Fig. 1 by employing Scherer's formula) phase was found to reach 45 and 40 nm, respectively. These results confirm that synthesized ferrite particles have nano metric structure.

Fig. 3(a, b) shows scanning electron micrographs (SEM) for the synthesized $SrFe_{12}O_{19}$ and $NiFe_2O_4$ samples. The micrographs clearly illustrate hexagonal platelet structure for $SrFe_{12}O_{19}$ and pyramidal one for $NiFe_2O_4$. The average particle size varies from 5 to 15 μm for both ferrites.

Comparing the ferrite powders morphologies (at Fig. 3); one can relate the changing outsides of these materials to their diverse solid-state transformation nature. In accordance with the Jonhson-Mehl-Avrami (JMA), kinetic model for the reaction rate of a solid-state transformation is:

$$\frac{d\alpha}{dt} = An(1-\alpha)[ln1/(1-\alpha)^{(n-1)/n}\exp(-E/RT)] \quad (1)$$

where α is the reacted molar fraction, t is the time for transformation, T is the absolute temperature, R is the world gas constant, E is the activation energy, A is the pre-exponential constant factor and n is the Avrami index parameter. The quantity of n depends on the material kind and it also controls the particles size and morphology. So, the Avrami index parameter changes by altering the ferrite and the particles morphology is also changed in turn [13–15].

3.2. . Magnetic properties

The magnetic properties of the nanostructure ferrite particles (after sintering) are shown in Fig. 4. The saturation magnetization of the ferrites was found to depend on their physical properties, increasing from 300 G (for $SrFe_{12}O_{19}$) to 350 G (for $NiFe_2O_4$) after sintering. The post-sintered coercivity of 1.8 kOe was observed for the $SrFe_{12}O_{19}$, where 0.02 kOe was measured for the $NiFe_2O_4$.

3.3. . Microwave absorption properties

Generally, microwave magnetic losses of magnetic particles originate from hysteresis, domain wall resonance, eddy current and ferromagnetic resonance. In the case of eddy current, the hysteresis loss is negligible for weak applied fields. Domain wall displacement loss occurs significantly in MHz ranges rather than that of GHz ones. Therefore, the contribution of domain wall resonance can also be excluded. The eddy current loss, which is related to the thickness and electric conductivity, can be ignored due to the ferrites nonconductive

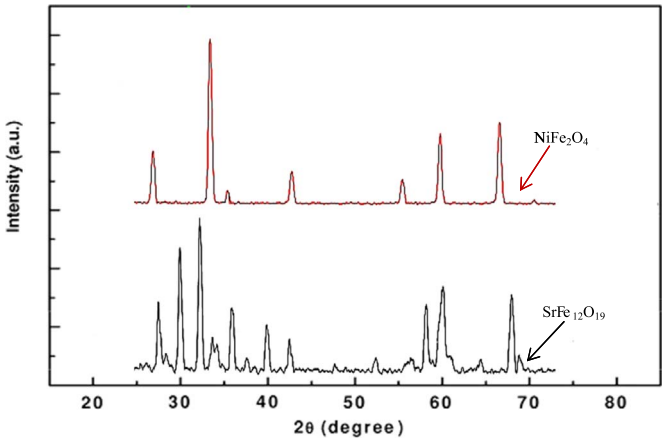

Fig. 2. XRD patterns of the $SrFe_{12}O_{19}$ and $NiFe_2O_4$ nanostructure particles (after sintering).