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Fabrication of multilayer chip inductors using Ni–Cu–Zn ferrites

T. Krishnaveni, B. Rajini Kanth, V. Seetha Rama Raju, S.R. Murthy *

Department of Physics, Osmania University, Hyderabad 500 007, India

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Abstract

Ni–Cu–Zn ferrite nanopowders were synthesized by co-precipitation method using microwave–hydrothermal (M-H) reaction system. The ferrite formation conditions such as pH, temperature and time were determined in detail according to the reaction conditions. The phase identification, crystallinity and morphology of the prepared samples were characterized by X-ray diffraction (XRD) and transmission electron microscopy (TEM). Nanocrystalline ferrites with high surface area were synthesized at temperatures as low as 165 °C in a short time (30 min). The nanoferrite powders were sintered at different sintering temperatures from 800 to 950 °C for 6 h using conventional sintering method. The performance of the sintered Ni–Cu–Zn ferrites has been estimated from the studies of dependence of permeability spectra on the frequency and temperature. Multilayer chip inductors were fabricated from the ferrite using the screen-printing method. Inductance and quality factor of the prepared inductors were measured over a wide frequency range.

Keywords: Ferrites; Nanocrystalline materials; Microwave-hydrothermal synthesis; Dielectric properties; Multilayerchip inductors

1. Introduction

Chip inductors are one of the passive surface mount devices (SMD). They are important components for the latest electronic products such as cellular phones, video cameras, notebook computers, hard and floppy drives, etc., and that require small dimensions, lightweight and better functions [1]. The traditional wire-wound chip inductors can only be miniaturized to a certain limit and lack of magnetic shielding leads to the development of new materials for the multilayer chip inductors. In this process only Ni–Cu–Zn ferrites were developed as the material used for the chip components [2–4], which can be fired at 900 °C or below. But, it was found that these ferrites are comparatively sensitive to stress and magnetic properties are easily changed or deteriorated by the stress caused at the internal electrode.

These problems can be reduced by the preparation of Ni–Cu–Zn ferrites using nanoferrite powders and then sintering under controlled experimental conditions. Komarneni et al. [5–8] have used the microwave-hydrothermal (M-H) method to prepare nanoparticles of various ferrites with high surface area. However, their studies were confirmed only to simple ferrites. Therefore, in the present investigation nanopowders of Ni–Cu–Zn ferrites were synthesized using M-H method. These nanopowders were sintered at different temperatures from 800 to 950 °C for 6 h using a conventional sintering method and their electrical and magnetic properties have been measured.

The multilayer chip inductors (MLCIs) are usually prepared either by the thick film screen-printing method [9] or by the process of green sheet lamination [10]. The MLCIs are fabricated with printed internal conductors connected among the ferrite layers in a coil style. The monolithic structure of the multilayer chip inductors demonstrates the superb capability of miniaturization and perfect closed magnetic circuit inside the chips [11]. Hence, no cross talk occurs when they are utilized in high-density electronic circuits. In the present paper multilayer chip inductors were fabricated using the screen-printing method with the prepared Ni–Cu–Zn ferrites. The performance of prepared multilayer chip inductor was also examined.

* Corresponding author.
E-mail address: ramanasarabu@yahoo.com (S.R. Murthy).

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2. Experimental method

Pure (99.99%) nickel nitrate [$Ni(NO_3)_2 \cdot 6H_2O$], copper nitrate [$Cu(NO_3)_2 \cdot 3H_2O$], zinc nitrate [$Zn(NO_3)_2 \cdot 6H_2O$] and iron nitrate [$Fe(NO_3)_2 \cdot 9H_2O$] were dissolved in 50 ml of deionized water. The molar ratio of powders was adjusted to obtain composition $Ni_{0.53}Cu_{0.12}Zn_{0.35}Fe_2O_4$. An aqueous NaOH solution was added to this solution until the desired pH ~9.45 was obtained. Proper control of the pH is the key factor in synthesizing the ferrites.

The mixture was then treated in a Teflon-lined vessel using a microwave digestion system (Model MDS-2000, CEM Corp., Mathews, NC). This system uses 2.45 GHz microwaves and can be operated at 0–100% full power (630 ± 50 W). The time, pressure and power were computer-controlled. The products obtained were filtered and washed repeatedly with deionized water, followed by drying overnight. The prepared powders were weighed and the percentage yields were calculated.

All the synthesized nanocrystalline ferrite particles were characterized using powder X-ray diffractometry. Particle size and morphology were determined using transmission electron microscopy (TEM).

The nanocrystalline particles of the prepared ferrite powder were mixed with an appropriate amount of 2 wt.% polyvinyl alcohol as a binder. Then the powder was uniaxially pressed at a pressure of 1500 kg/cm^2 to form green pellet and toroidal specimens. After the binder burnt out at 600 °C for 2 h, the compacts were conventionally sintered at 800 °C/6 h (sample No. 1), 850 °C/6 h (sample No. 2), 900 °C/6 h (sample No. 3) and 950 °C/6 h (sample No. 4) in air. The final composition of the ferrite as estimated from chemical analysis was $Ni_{0.53}Cu_{0.12}Zn_{0.35}Fe_2O_4$. The electrical properties were measured using HP4194 impedance analyzer in the frequency range of 1–100 MHz. The permeability and quality factor were calculated using the standard procedure from the measured inductance and magnetic loss of the coil wound toroids. The saturation magnetization has been measured using vibrating sample magnetometer (VSM).

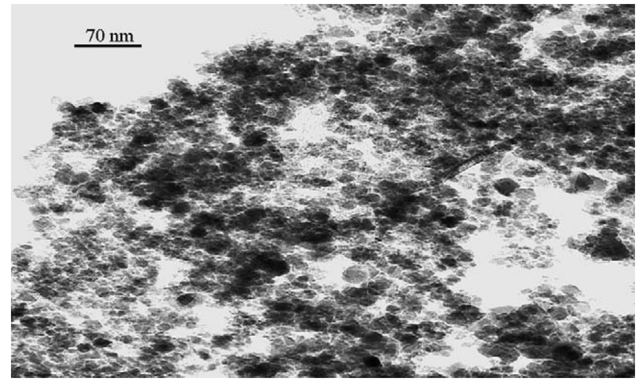

Fig. 2. TEM picture of Ni–Cu–Zn ferrite.

The MLCIs were fabricated using the screen-printing method. The prepared chip inductors were fired to 890 °C/4 h, 900 °C/4 h, and 910 °C/4 h, respectively, and the obtained results were presented in this paper.

3. Results and discussion

Fig. 1 shows the powder XRD result of microwave-hydrothermally synthesized sample. It is clear from the figure that the sample is nanocrystalline in nature. Fig. 2 shows the TEM analysis of the synthesized powder. The particle size of the synthesized powder is about ~10–30 nm in size and exhibited more or less spherical morphology.

Fig. 3 shows the XRD patterns for the sintered Ni–Cu–Zn ferrites. It can be seen from the figures that all the samples possess mono-phase in nature. The average value of lattice constant calculated from these X-ray data is found to be

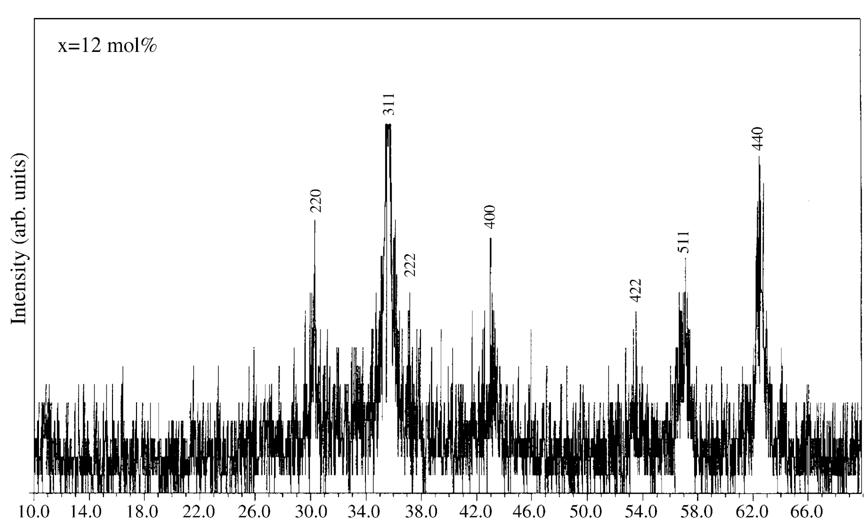

Fig. 1. XRD patterns of M-H-synthesized nanophase Ni–Cu–Zn ferrite powders.