Dielectric Behavior of Nickel-Zinc Dopped Hexagonal W-type Barium Ferrite

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Abstract

A prepared compound of $BaZn_{2-x}Ni_xFe_{16}O_{27}$ (X=0, 0.5, 1, 1.5 and 2) is synthesized in polycrystalline form, using the stoichiometric mixture of oxides with conventional ceramic technique and characterized by X-ray diffraction. Analysis confirmed the presence of W-type hexagonal ferrite. The conductivity, dielectric constant and loss tangent (tanδ) were measured as a function of frequency taken between (100Hz-6MHz) at room temperatures and compositions. It was observed the ac conductivity is independent of frequency approximately for f < log 4.5 but if the frequency was greater than previous values then the conductivity increases strongly with frequency for all compositions, the electrical mechanism was explained in terms of the electron hopping mode. Moreover, the dielectric constant and dielectric loss factor decrease with frequency of applied electric field.

Keyword: Hexaferrite, Solid-state reaction method, Dielectric behavior, XRD.

Introduction

An interesting series of ferrimagnetic oxides with hexagonal structures was extensively studied by Jonker and his coworkers [1]. Worldwide interests have been focused on microwave absorbing materials in recent years, due to the obvious increase in the use of electronic and electric devices, resulting in the serious pollution of electromagnetic waves [2]. There is a considerable interest in different types of hexagonal ferrites, due to their applications in our every day life such as home applications, electronic devices, communication equipments and computers [3,4]. Polycrystalline hexaferrites are very useful for microwave applications due to its very low dielectric loss [5].

The crystal structure of six possible different type of hexagonal ferrite M, W, Y, Z, X and U is very complex. The simplest material structure, is the so called M-type the formula $BaFe_{12}O_{19}$. Among the hexagonal, W-type compounds with a general formula $AMeFe_{16}O_{27}$ (A= alkali earth metals, usually Ba, Sr, Ca and Me = metals like Zn, Co, Ni, etc.). The unit formula structure of this type is $SSR^*S^*\ S^*R$, the "blocks" S, R, S^* and R^* are designated; the S-block has the formula Fe_8O_{16} and R-block $BaFe_8O_{11}$ between S and S^*, and between R and R^* a 180° rotation about the c-axis occurs [1,6].

In the W-hexaferrites the dielectric properties can be varied in a wide range by a suitable choice of additionally occurring divalent cations, without changing iron content. Besides different a content of substitutions, in the presents paper, the study of electrical properties of $BaZn_{2-x}Ni_x$-W ferrite are reported with a view to study the effect of substitution on the behavior of ferrite.

Experimental Techniques

A polycrystalline Ba hexagonal ferrite with composition formula $BaZn_{2x}Ni_xFe_{16}O_{27}$, (where X= 0, 0.5, 1, 1.5 and 2) was prepared by the conventional ceramic technique [7].

Each of pure $BaCO_3$, ZnO and NiO were supplied by redel-De Haen Germany Company with high purity (more than 99%) and Fe_2O_3 supplied by BDH chemicals Ltd Pool (England) with purity >99% used as start materials. Stoichiometric ratios of these materials were grounded in a gate mortar for two hours and then heated at $900\ C^{\circ}$ for two hours. The mixture were grounded again to a very fine powder by using a gate mortar for about two hours, pressed into pellets of diameter about 16mm and thickness 6 mm under a pressure 14.6 MPa, after that, the pellets were fired in two stages in an electrical furnace at atmospheric condition, firstly at rate $5\ C^{\circ}/min$ up to $500\ C^{\circ}$, secondary with rate $5\ C^{\circ}/min$ up to $1200C^{\circ}$ and soaked for 4 hours, then, cooled to room temperature.

The real and imaginary parts of the dielectric constant as electrical conductivity

measurements were carried out using LCR meter model 4194A made in Japan.

The electrical measurements were carried out in the range from 100 Hz to 6MHz, using LCR meter. The dielectric constant ε_r was calculated using the formula

$$\varepsilon_r = \frac{C \times d}{\varepsilon_\circ A} \text{...} (1)$$

where, C is capacitance of pellet in Farad, d is the thickness of pellet in meter. A, is the cross section area of the flat surface of the pellet and $\varepsilon_\circ$ is a constant of permittivity of free space.

Also, the value of loss factors for test samples is given by tan δ.

In addition, ac conductivity were carried out for all ceramic samples at room temperature in the same range of the frequency, $\sigma_{a.c}$ measurement can be calculated by following the equation [3,4,8]:

$$\sigma = 2\pi f \varepsilon_\circ \varepsilon_i \text{...} (2)$$

Where, σ is the conductivity $(\Omega.m)^{-1}$, ε_i is imaginary part of dielectric constant (F/m), f is the frequency (Hz).

Results and Discussion

X-ray diffraction analysis (XRD) was done at room temperature to determine the present phases. Philips 1710 diffractometer was used with Cu-Kα radiation ($\lambda = 1.5418$ Å) operated at 40 kV and 20 mA and over a wide range of Bragg angle ($20^\circ \leq 2\theta \leq 60^\circ$). Fig. (1) shows a polycrystalline W-type ferrites structure was prepared by conventional method for ceramic as mentioned before.
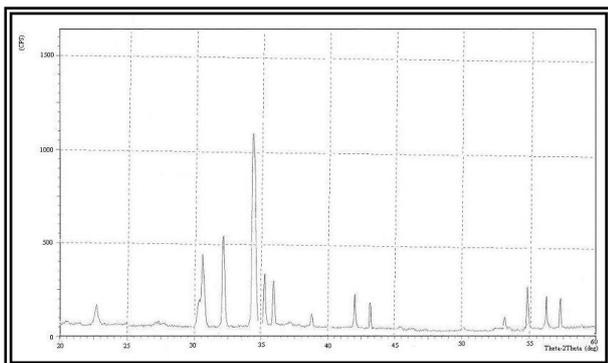
Fig. (1) X-ray diffraction patterns for BaZnNiFe$_{16}$O$_{27}$.

Fig.(2) is a typical curve which correlates the variation of the real part of dielectric constant ε as a function of frequency (100Hz-6MHz) for the mixed ferrite BaZn$_{2-x}$Ni$_x$Fe$_{16}$O$_{27}$ with different compositions of X=0, 0.5, 1, 1.5 and 2. The figure shows the frequency dependence of the dielectric constant at room temperature for the prepared samples. We can see obviously, a traditional dispersion or decrease of dielectric constant with increasing frequency, and this behavior is always attribute to the lagging of the existing charge carriers (hopping electrons) between Fe^{2+} and Fe^{3+} ions at localized sites; where the Fe^{2+} were formed in the samples during the sintering process at elevated temperature, responsible for polarization behind the applied field as its frequency increased [9,10].
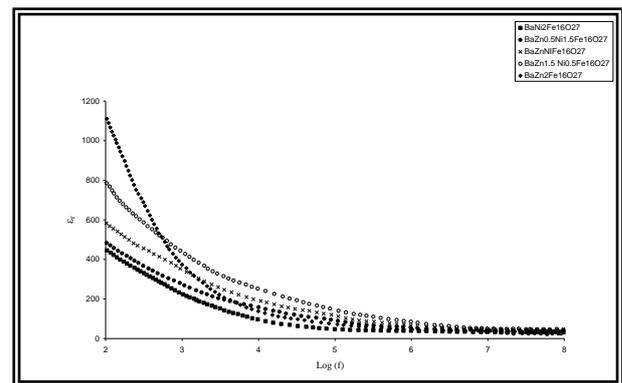
Fig. (2) Frequency dependence of dielectric cons-tant as a function for investigated compositions.

From the same figure, one can be noticed in generally the dielectric constant value are high particularly at low frequencies, thus can be attributed to interracial polarization known to occur in heterogeneous structures [11].
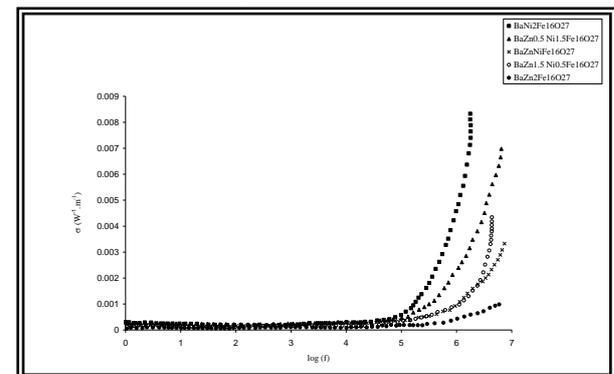
Fig. (3) Frequency dependence of conductivity as a function for investigated compositions.

Fig.(3) shows the variation of a.c conductivity with frequency for the prepared samples. It is known that, there is a strong correlation between the conduction mechanism and the dielectric constant behavior in ferrite. We can explain the behavior of $\sigma_{a.c}$ with frequency in terms of polarization effect and hopping i.e., polarization effect in low frequency region where polarization is slightly changed and $\sigma_{a.c}$ is dominated, and at higher frequency region the hopping which take place and conduction process shows an over linear behavior because of heterogonous distribution of the barrier height or its attributed to the relaxation from the polycrystalline for the centers at low temperature [12]. Fig.(4) shows us the loss tangent behavior as a function of frequency at room temperature for all samples. The loss tangent (tanδ) is defined as ratio of the loss or resistive current to the charging current in the sample [13].It is known that, there is a strong correlation between the conduction mechanisms and the dielectric constant behavior in ferrite. From these two considerations we can see the behavior of tanδ with the frequency is showing the expected decrease tan δ with increasing frequency.
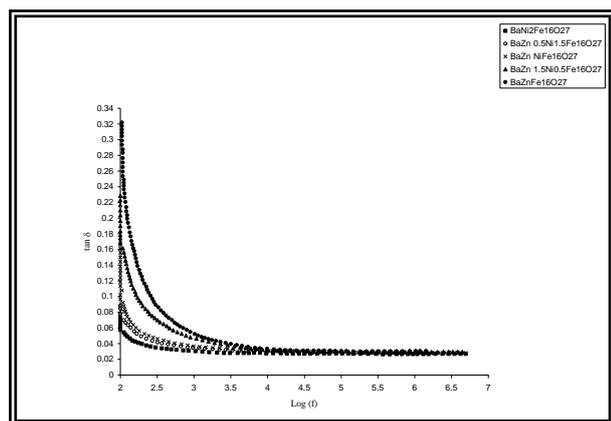
Fig. (4) Frequency dependence of loss tangent as a function for investigated compositions.

Conclusion

The main conclusions that can be drawn from the results are:

- Magnetoelectric hexagonal W-type are fabricated from stiocometric ratio of high pure $BaCO_3$, ZnO, NiO, and Fe_2O_3 oxides by the conventional ceramic sintering process.

- The ac electrical conductivity increases while the dielectric constant (ε_r) and dielectric loss factor (tan δ) decreases as frequency of the applied electric field increases then reaches a constant value for all samples.

- The relatively high values of the dielectric constant at low frequencies are due to the interfacial polarization ensuring that the samples can be fairly considered as formed of well conducting grains and poorly conducting grain boundaries in agreement with Maxwell-Wignner theory with Koop's model.

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الخلاصة

تم تحضير مركب متعدد التبلور نوع

$BaZn_{2-x}Ni_xFe_{16}O_{27}$ حيث x تأخذ القيم

(0,0.5,1,1.5.2) , استخدمت التقنية التقليدية في تحضير السيراميك لخليط متناسب من الاكاسيد المكونة للمركب، تم التأكد من أطوار التركيب بواسطة تقنية حيود الأشعة السيني ة، حيث وجد بان التركيب المحضر هو سداسي نوع W-type. تم قياس كل من التوصيلية ، ثابت العزل ومعامل الفقد كدالة للتردد مابين 100هرتز− 6 ميكاهرتز وعند درجة حرارة الغرفة بالإضافة إلى تركيز المكونات وقد لوحظ بان التوصيلية تكون ثابتة تقريبا عند ترددات اقل من Log4.5 ولكن عند قيم الترددات الأعلى من التي ذكرت سابقا فالتوصيلية تزداد بشدة بزيادة التردد لكل المكونات الفرايتية. إن ميكانيكية التوصيل تم توضيحها بمصطلح قفز الاكترون بينما ينخفض كل من ثابت العزل ومعامل الفقد بزيادة تردد المجال الكهربائي المسلط.