Study the electrical and magnetic properties of Ferrite Ni$_{1-x}$Zn$_x$Fe$_2$O$_4$ films and their potential use in the magnetic core of transformers.

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Abstract: Membranes (Ni$_{1-x}$Zn$_x$Fe$_2$O$_4$) were prepared by chemical precipitation method and with different weight ratios of values (x = 0, 0.3, 0.5, 0.7, 0.9), the electrical properties of the prepared samples were studied with the presence of a magnetic field of magnitude (0.45T), the result (Hall Effect) The majority of charge carriers are electrons, while the results of magnetic tests showed that the prepared films of different weights are of a type (soft Ferrite) The membranes behaved as a ferromagnetic material. The results indicate that the membranes can be used in the fields of microwave frequencies and in the transformers inside the magnetic core due to the smallness of the hysterical loop.

Keyword: Ferrites, Hall effect, Magnetic retardation, Magnetic torque

1. Introduction

By discovering a stone from the so-called nature Magnate, the ancient Greeks found a magnet in the city of Magnesia in the century (600 BC). The scientist Gilbert, who wrote a book about this area entitled (Fe$_3$O$_4$), was one of the first pioneers in the field of magnetism in (1600 AD) (Demagent), It’s also one of the first studies to provide a conceptual connection between magnetic properties and chemical compositions of materials, He investigated various forms of ferrites as well as the interaction between the Curie temperature and the structure and form of magnetic materials, and then pursued further study based on his findings, In 1945, the first Freight was economically and industrially generated. [1]. Ferrites are non-metallic materials but are complex ionic oxide compounds of various minerals with a dark gray or black color derived from magnetite (iron oxide). There are three types of Ferrite materials (Spinel Ferrite, Agate Ferrite, and Hard Ferrite), where the chemical composition of the Ferrite compounds enters into their structural, magnetic and electrical properties [2]. Vertical films are used in multiple technology applications such as sensors and electromagnetic interference devices [3], Gas sensors [4]. And also in storing information [5]. The electrical and magnetic properties of the filtrate appear as a result of the interaction of different metallic ions that occupy a specific place with respect to the basic oxygen ion in the composition of the oxide crystal. And it has electromagnetic characteristics as it is characterized by easy
magnetization and high electrical resistance in excess of the resistance of materials with high magnetic permeability as well as it has a high insulation constant [6]. Ferrites have different crystal structures, and in their form are soft or hard ferrites, the weak ferrite is the main material in the manufacture of electrical transformer cores, and the (nickel-zinc) fruity is a weak ferrite [7]. Substituting part of the nickel oxide in the (nickel-frit) compound with zinc oxide improves the magnetic and electrical properties of the compound and makes it work in a wider frequency range [8]. The crystal structure, magnetization amount, and dielectric properties of Frit depend on the preparation method and the concentration of additives, And impurities that are often used by the method of solid state reactions in the preparation of these materials, and it is preferable to choose raw materials with high purity not less than (99%) [9].

2. The experiment

2.1 Materials used and method of work

Materials with a very high purity (99.99%) were used for the purpose of studying the electrical and magnetic properties of the Ferrite complex used in the experiment. The materials were mixed in appropriate weight ratios with a small amount of distilled water for a period of three hours for the purpose of preparing NiFe2O4 of nickel salts, nickel oxalate, and its molecular weight (176.85), And from iron chloride (FeCl3) and its molecular weight (162.21) To complete the mixing process using a magnetic mixer, Continuing mixing, ammonium hydroxide (NH4OH) was added in order to reach PH≥ 8, And put the mixture in an electric oven at a temperature of (700 ºC) To complete the calcination process and leave for a whole day to cool in the oven After that, the mixture was crushed and screened to obtain a homogeneous mixture, In the same way, ZnFe2O4 ferrites were prepared from iron chloride and zinc oxalate (ZnC4H6O.2H2O) Of a molecular weight (219.49), To obtain the weight to be removed, we use the following relationship:

\[
m = \left( \frac{W_t}{M_{wt}} \right) \left( \frac{1000}{V} \right)
\]  

\( M_{mol} \) = Molar concentration 1/mol, \( W_t \)= the required weight is dissolved in gram, \( M_{wt} \)= Molecular weight of the substance gm/ mol, \( V \)= the volume of distilled water used for dissolution [10].

2.2 Electrical measurements

(Hall Effect) is one of the main methods for studying electrical properties and is named after its researcher (E.Hall). As he was the first to see it in 1879 on metal foil, And it is achieved by applying a magnetic field BZ to a semiconductor direction perpendicular to the direction of conduction of an electric current (Ix) Charge carriers have a tendency to deviate sideways, which creates a voltage difference across the semiconductor in a direction perpendicular to both the direction of the current and the magnetic field It is called the Hall voltage, and it is accompanied by an electric field called the Hall field. The Hall coefficient is calculated from the mathematical relationship:

\[
R_H = \left( \frac{V_H}{I_X} \right) \left( \frac{t}{B_Z} \right)
\]  


Hall coefficient (RH) is negative for (n-type) semiconductors and positive for (p-type). 

\( V_{H}/I_x \) represents the linear relationship between Hall voltage \( V_H \) and the amount of output current \( I_x \), \( B_z \) the intensity of the impressed magnetic field, \( t \) thickness. The concentration of charge carriers and mobility are calculated from relationships:

\[
 n = \frac{1}{RH \cdot e} \quad \text{(3)}
\]

\[
 \mu_H = \frac{\sigma}{n e} = \sigma |RH| \quad \text{(4)}
\]

Where \( e \) is the charge of the electron, \( \sigma \) conductivity measured in \((\Omega \cdot \text{cm})^{-1}\), \( \mu_H \) Mobility, measured in units \((\text{cm}^2/\text{V.s})\)\([11,12]\). Aluminum foil was used to manufacture the masks for deposition of the electrodes to measure its Hall Effect with a suitable size with the size of the thin film as shown in Figure 1. Four small holes with dimensions \((2 \times 2) \text{ mm}\) were made to prepare the aluminum masks, and they were installed on the front part of the floors on which the membrane material was deposited in order for the electrodes to be deposited over them with the thermal evaporation deposition technique.

![Figure 1](image)

**Figure 1.** (a) Deposition mask diagram for the Hall Effect experiment (b) The sample is after deposition of the aluminum electrodes to test the Hall Effect

3. Discuss the results

3.1 (Hall Effect)

Hall results for membranes with gravitational ratios showed the existence of a constant magnetic field of \((0.45 \text{ Tesla})\) vertically, and through the Hall voltage generated at both ends of the membrane, it was possible to calculate the movement of carriers, to know the type of charge carriers and calculate their concentration. Hall effect carries a negative charge for all membranes, which means that the majority charge carriers are electrons. Through Figure 2, we see the highest conductivity at the weight ratios \((x = 0.9)\) due to the substitution behavior of the atoms in the two materials used in the preparation. We observe an increase in Hall's mobility with an increase in distortion and a decrease in resistance, due to a linear increase in the charged electrostatic barrier caused by the captured carriers, which leads to the dispersion of the charge carriers and impedes the mobility. Figure 3, also indicates the relationship between mobility and the concentration of charge carriers as a function of deformation percentages. Table No. 1, Shows the results that we reached through practical measurements.
Figure 2. illustrates the conductivity as a function of gravitational ratios

Figure 3. the relationship between mobility and concentration of charge carriers

Table 1. Shows the results of the electrical calculations for the blocked films with different weight ratios of Ni$_{1-x}$ZnxFe$_2$O$_4$.

| Value-X | Bulk concentration l/cm$^3$ | Mobility cm$^2$/v.s | Average Hall Coefficient cm$^3$/c | Conductivity 1/Ω.m | Resistivity Ω.m | Type |
|---------|-----------------------------|----------------------|----------------------------------|---------------------|---------------|------|
| 0.0     | -3.45x$10^{-11}$            | 3.06x$10^{+1}$       | -1.40x$10^{-7}$                  | 3.01x$10^{6}$       | 3.32x$10^{5}$ | n-Type |
| .5      | -1.55x$10^{-11}$            | 1.18x$10^{+2}$       | -2.55x$10^{-7}$                  | 3.77x$10^{6}$       | 2.65x$10^{5}$ | n-Type |
| .6      | -1.29x$10^{+11}$            | 5.55x$10^{+1}$       | -1.87x$10^{-7}$                  | 3.967x$10^{6}$      | 2.52x$10^{5}$ | n-Type |
| .7      | -1.04x$10^{+11}$            | 5.07x$10^{+1}$       | -1.43x$10^{-7}$                  | 3.332x$10^{6}$      | 3.01X$10^{5}$ | n-Type |
| .8      | -4.87x$10^{+11}$            | 3.99x$10^{+2}$       | -1.04x$10^{-7}$                  | 5.47x$10^{6}$       | 1.995x$10^{5}$ | n-Type |
3.2 Magnetic findings

Figures 4(a ,b ,c ,d)) shows the results of the magnetic retardation of the prepared films in the proportions (x = 0, 0.3, 0.5, 0.7, 0.9) which are of the type (soft Ferrite), notice that the area of the vaginal ring increases with the increase in the rate of deformation, through the results listed in Table No. 2, in which we list the magnitude of the magnetic parameters, which are magnetic saturation (Ms), Magnetic Retardation (Mr), Force Coercive (Hc), and The magnetic moment calculated from equation (5),Where we notice the decrease in the force of compulsory saturation (Hcs), while the magnetic moment is constantly increasing with the increase of the deformation ratio. The films acted as ferromagnetic materials, and this is consistent with the findings of the researchers Almammori and (Reghvender) mechanism [13, 14]. We also note the smallness of the hysteresis loop, which leads to the possibility of using membranes in the fields of microwave frequencies and in transducers inside the magnetic core.

\[
\mu B = M_{wt} \cdot MS \\
\]

Where \( \mu B \) stands for magnetic moment, \( M_{wt} \) is molecular weight, \( MS \) magnetic saturation \[15\].

**Table 2.** The results of magnetic tests for Ni\(1-x\) Zn\(x\)Fe\(2O4\) films

| Value-X | Ms (emu/gm) | Br(T)  | B(T)  | Hc(A/m) | \( \mu B \)  |
|---------|-------------|--------|-------|---------|-------------|
| 3.3     | 0.0073      | 0.0096 | 0.0106 | 0.008   | 0.0073      |
| 3.0     | 0.0188      | 0.153  | 0.0283 | 0.0157  | 0.0188      |
| 0.7     | 14.5        | 16.80  | 33.5  | 50.6    | 14.5        |

The best magnetic specifications for using the material as magnetic cores is that the material has a high magnetic permeability, which is derived from \( B_{max} \) of a high value, as well as the residual magnetic (Br) in addition to the lowest possible value of the magnetic catalyst (Hc) so that it does not exceed (0.5 m / A) in order for the hysteresis loop to be narrow and thus its area to be small and then the wasted energy becomes as little as possible. The magnetic diaphragm (Hc) is high so that the material does not lose its magnetism easily in addition to having a high residual magnetism (Br).
Figure 4a. the magnetic hysteresis loop of Ni$_{1-x}$Zn$_x$Fe$_2$O$_4$ films at X=0

Figure 4b. the magnetic hysteresis loop of Ni$_{1-x}$Zn$_x$Fe$_2$O$_4$ films at X=0.3

Figure 4c. the magnetic hysteresis loop of Ni$_{1-x}$Zn$_x$Fe$_2$O$_4$ films at X=0.5
Conclusions

The results of the electrical properties tests of the membranes prepared for the compound (Ni$_{1-x}$ Zn$_x$Fe$_2$O$_4$) showed that the Hall Effect is of the negative type, meaning that the majority charge carriers are electrons. Resistivity increases with increasing zinc concentration while Hall mobility decreases with increasing concentration in deformation. As for the magnetic results, they showed that the prepared films are of the type (soft Ferrite) and have the ability to control the magnetic hysterical ring and their magnetic characteristics can be controlled through deformation ratios and thus can be used in different applications.

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