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Study of DC conductivity and relative magnetic permeability of nanoparticle $NiZnFe_2O_4$/PPy composites

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ABSTRACT

The DC conductivity and the relative magnetic permeability have been measured as functions of temperature for five powder samples of nanoparticle ferrites ($Ni_xZn_{1-x}Fe_2O_4$; $x=0$, 0.25, 0.5, 0.75 and 1), a pure polypyrrole (PPy) powder sample and many composite samples prepared by mixing different ratios of the ferrites to PPy. By comparing the results it is found that there is an obvious increase in DC conductivity of the ferrite/PPy composite samples compared to the corresponding pure ferrite samples, whereas compared to the pure PPy sample there is a decrease in DC conductivity. On the contrary, the magnetic permeability of the composites is higher than that of the pure PPy sample and lower than that of the pure ferrite samples as was expected.

1. Introduction

Conducting polymer composites have many promising applications in a variety of electric and electronic devices. These materials with some suitable compositions of one or more insulating materials can be tailored to exhibit desirable properties. The present work composites are especially important owing to their bridging role between the world of conducting polymers and that of magnetic nanoparticles [1] or in other words, if suitably tailored, they may give complementary behavior between polymers and the inorganic magnetic nanoparticles [2]. Among the new applications of conducting polymers–magnetic nanoparticles composites are electro-chromic devices, electromagnetic interference shielding, rechargeable batteries, sensors, electrochemical display devices and nonlinear optical systems [3,4]. An example of performed researches in this field is the work of Murugendrappa and Prasad [1] who had polymerized PPy in the presence of γ-Fe_2O_3 to synthesize polypyrrole/γ-Fe_2O_3 composite. They had investigated the AC conductivity and the dielectric behavior in the frequency range 10^2–10^7 Hz. Whereas, Jiang et al. [3] had prepared polypyrrole/$Zn_{0.5}Cu_{0.5}Fe_2O_4$ nanocomposite by polymerization of PPy in the presence of $Zn_{0.5}Cu_{0.5}Fe_2O_4$ nanoparticles. Their prepared samples were investigated by XRD, IR, SEM and vibrating sample magnetometer (VSM). Results showed that the magnetic parameters such as saturation magnetization and coercivity of $Zn_{0.5}Cu_{0.5}Fe_2O_4$ have decreased upon PPy coating. Nathani and Misra [5] and Nathani et al. [6] had studied magnetic properties of nanocrystalline nickel ferrite–polyethylene nanocomposites synthesized by the mechanical milling process and they suggested the superparamagnetic nature of the nanocomposites because of the absence of hysteresis, remanence and coercivity at room temperature.

The aim of the present work is to report and discuss a comparative study of the DC electrical conductivity and the magnetic permeability of pure ferrites ($Ni_xZn_{1-x}Fe_2O_4$), pure polypyrrole (PPy) and composite samples of ($Ni_xZn_{1-x}Fe_2O_4$/PPy) with different weight ratios. Such a study had not been reported before despite it may be of considerable importance for material designers for practical applications.

2. Experimental

Ultrafine particles of $Ni_xZn_{1-x}Fe_2O_4$ ($x=0.0$, 0.25, 0.5, 0.75, 1) were synthesized by a chemical co-precipitation method; the details of preparation of the samples and characterization by X-ray diffraction analysis and IR spectroscopy were previously explained [7]. From the XRD data the crystallite sizes were calculated. Moreover, in the present paper as a confirmation of the nanosize nature of ferrite samples, SEM images have been taken for two randomly chosen samples: $Ni_{0.5}Zn_{0.5}Fe_2O_4$ and $NiFe_2O_4$.

PPy has been chemically polymerized by anhydrous ferric chloride. Two groups of ferrite/PPy composites have been prepared by manual mixing and thoroughly grinding in an agate mortar. The first group of composites have been prepared using different weight ratios of $Ni_{0.5}Zn_{0.5}Fe_2O_4$/PPy and the second group have been prepared using one ratio 40 wt% of different ferrite compositions ($Ni_xZn_{1-x}Fe_2O_4$) to 60% wt of PPy. The compositions and ratios of the constituents of the two groups are listed in Tables 1 and 2, respectively. The PPy sample and composite samples have been characterized by IR spectroscopy.

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Table 1
The constituents of the first group of composites.

First group of composites	$Ni_{0.5}Zn_{0.5}Fe_2O_4$ wt%	100%	80%	60%	40%	20%	0
	PPy wt%	0	20%	40%	60%	80%	100%

Table 2
The constituents of the second group of composites.

Second group of composites	60% PPy	40% $ZnFe_2O_4$	40% $Ni_{0.25}Zn_{0.75}Fe_2O_4$	40% $Ni_{0.5}Zn_{0.5}Fe_2O_4$	40% $Ni_{0.75}Zn_{0.25}Fe_2O_4$	40% $NiFe_2O_4$

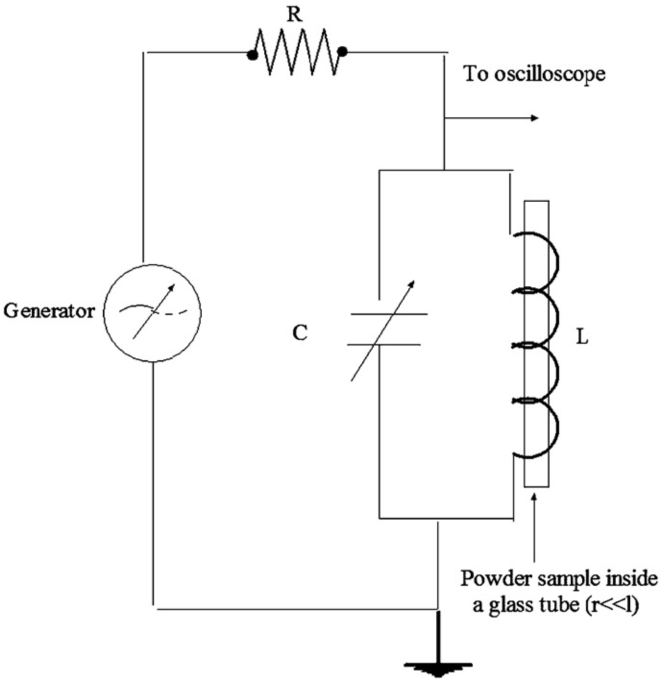


Fig. 1. The resonance circuit for measuring permeability.

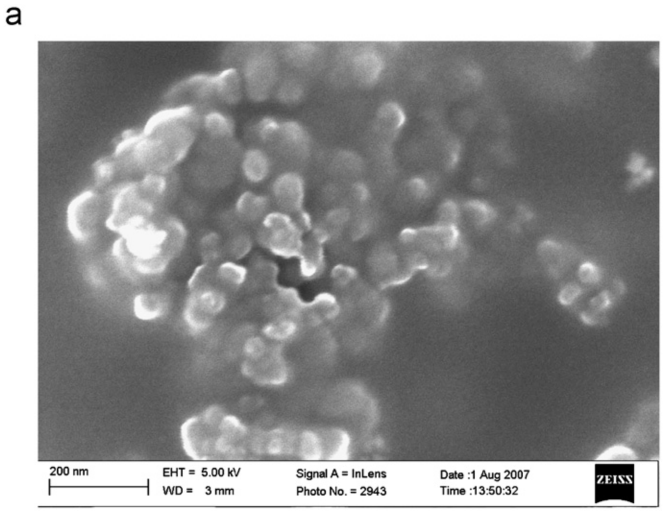
Measurements of DC electrical conductivity and its variation with temperature have been carried out by a two probe circuit in the temperature range (300–505 K) for pure ferrite samples and (308–358 K) for PPy and composite samples.

The relative magnetic permeability (μ_r') has been determined using two methods. In the first method, μ_r' has been calculated by measuring the mass susceptibility of all the samples (MS2B Magnetic Susceptibility Meter-Bartinglon Instrument Ltd.) at room temperature. In the second method, the relative permeability has been determined, as a function of temperature (in the range of 295–700 K for pure ferrites and 295–393 K for PPy and composite samples), using a home-made resonance circuit (Fig. (1)), where μ_r' is given by $\mu_r' = L_s/L_0$ [8] (L_0 and L_s are the inductance of the solenoid in the resonance circuit without and with sample inside, respectively).

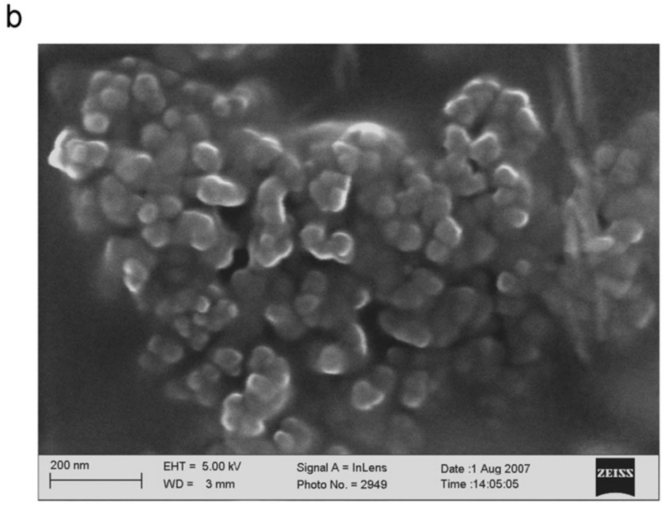
3. Results and discussion

3.1. Structure

Fig. 2 shows the scanning electron microscope (SEM) images of two ferrite samples as a confirmation of the nanosize of the particles. Table 3 shows the "crystallite" (i.e. grain) sizes previously calculated from the X-ray charts [7] and the "particle" (i.e. Grain+grain boundary) size estimated from the SEM images. It can be observed that the estimated average "particle" sizes from the SEM images are in the desired nanosizes although they are larger than the corresponding "crystallite" sizes estimated from X-ray diffraction analysis, this is expected because it is well known that X-rays can detect the crystallites only, i.e., the well-ordered parts of the particles and they cannot detect the disordered grain boundaries, which occupy a considerable volume in the case of nanoparticles. Besides there is a probability of agglomeration of more than one particle such that they appear



$Ni_{0.5}Zn_{0.5}Fe_2O$



$NiFe_2O_4$

Fig. 2. The SEM images of two chosen samples.