Study on Humidity Sensitive Electrical Properties of Nickel Substituted Cobalt Zinc Ferrite for Humidity Sensor Application

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Abstract

Ferrites are humidity sensitive materials and therefore, Nickel substituted Cobalt-Zinc ferrites, $Co_{0.5x}Ni_xZn_{0.5}Fe_2O_4$ (where x = 0.0, 0.1, 0.2 and 0.3) were chosen and prepared by co-precipitation method for the applications of humidity sensing materials. Analar (AR) grade Nickel Chloride Hexahydrate ($NiCl_2.6H_2O$), Zinc Sulphate Heptahydrate ($ZnSO_4.7H_2O$), Cobalt Chloride Hexahydrate ($CoCl_2.6H_2O$) and anhydrous Ferric Chloride ($FeCl_3$) with desired stoichiometric compositions were used to prepare the samples. The precursor co-precipitated ferrites were annealed at 600°C for 2 h in vacuum chamber (160 mmHg). Humidity sensitive electrical properties of the samples were observed in the relative humidity range of 36 RH% - 98 RH% using FLUKE 189 digital multimeter. In this measurement, the refrigerator (TOSHIBA) was used as the humidity generator and XSW TDK 0302 was used as the humidity sensing element. It was found that the electrical resistance decreased with increase in humidity and the dc voltage and capacitance increased with increase in humidity.

Keywords: $Co_{0.5-x}Ni_xZn_{0.5}Fe_2O_4$, co-precipitation method, Humidity sensitive electrical properties

Introduction

Ferrites are insulating magnetic oxides. Spinel ferrites are extremely important for academic and technological applications. Spinel ferrites have been studied extensively due to their low prices, easy to fabricate and abundant uses in technological and industrial applications. The useful properties of the spinel ferrites mostly depend upon the chemical composition, preparation methods, sintering temperature, nature of the additives and their distribution i.e. tendency to occupy tetrahedral (A) or octahedral (B) site (Fawzi et al., 2010).

Humidity is the concentration of water molecules in the atmosphere. The main concern for many years in moisture sensitive areas such as high voltage engineering systems, food processing, textile manufacturing, storage areas, hospitals, museums, libraries and geological soil sample studies (Rani et al., 2013). In automobile industry, humidity sensors are used in rear-window defoggers and motor assembly. In medical field, humidity sensors are used in respiratory equipment, sterilizers, incubators, pharmaceutical processing, and biological products. In agriculture, humidity sensors are used for green-house plantation protection (dew prevention), soil moisture monitoring, and cereal storage. In general, humidity sensors are used for humidity control in chemical gas purification, dryers, ovens, film desiccation, paper and textile production, and food processing (Patil & Ladgaonkar, 2013).

Experimental Details

Preparation of Nickel substituted Cobalt-Zinc Ferrites

Nickel substituted Cobalt-Zinc ferrites with the general formula $Co_{0.5-x}Ni_xZn_{0.5}Fe_2O_4$ (where x = 0.0, 0.1, 0.2 and 0.3) were prepared by co-precipitation method. Aqueous

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solutions of Analar (AR) grade Nickel Chloride Hexahydrate ($NiCl_2.6H_2O$), Zinc Sulphate Heptahydrate ($ZnSO_4.7H_2O$), Cobalt Chloride Hexahydrate ($CoCl_2.6H_2O$) and anhydrous Ferric Chloride ($FeCl_3$) with the respective stoichiometry were mixed thoroughly stirrer at 80°C using magnetic-stirrer. It was then transferred immediately into a boiling solution of Sodium Hydroxide (NaOH) under stirring throughout the reaction. Conversion of metal salts into hydroxides and subsequent transformation of metal hydroxide into ferrites take place upon 100°C and maintained for 1 h until the reaction was completed. The ferrites thus formed were isolated by centrifugation and washed four times with de-ionized (DI) water followed by acetone and then dried at room temperature. The dried ferrites powders were ground by laboratory-made ball-milling machine and then annealed at 600°C for 2 h in vacuum chamber (160 mmHg) by using thermal resistive heating coil. DELTA A Series Temperature Controller DTA4896 and the K-type thermocouple were used as the temperature controller and temperature sensor for the sample preparation. Experimental set-up of sample preparation system is shown in Figure (1).

Fig 1 Photograph of the experimental setup of sample preparation system

Humidity Sensitive Electrical Properties Measurement

Humidity sensitive electrical properties of the $Co_{0.5-x}Ni_xZn_{0.5}Fe_2O_4$ (where x = 0.0, 0.1, 0.2 and 0.3) samples were investigated in the relative humidity range of 36 RH% - 98 RH% for the applications of humidity sensors. Firstly, the as-prepared ferrites were made circular shape pellets by SPECAC hydraulic pellet-maker using the pressure 5 ton (~70 MPa). Then the pellet was polished to get the smoothing surface. Dimensions of the samples were measured by using digital Vernier-Caliper (Taiwan). Photographs of the thickness measurement of $Co_{0.5}Zn_{0.5}Fe_2O_4$ (x = 0.0) sample pellet and experimental setup of humidity sensitive electrical properties measurements are shown in Figure 2(a – c). Thicknesses of the samples are listed in Table 1. Area of the each of the sample was used as 1.14×10^{-4} m^2. The sample was then fixed on glass plate and silver contacts were made over the sample to ensure good electrical contact.

In this measurement, the refrigerator (TOSHIBA) and XSW TDK 0302 were used as the humidity generator and the humidity sensing element. Humidity sensitive electrical resistance, voltage and capacitance of the sample were observed by two probe method by using FLUKE 189 digital multimeter.

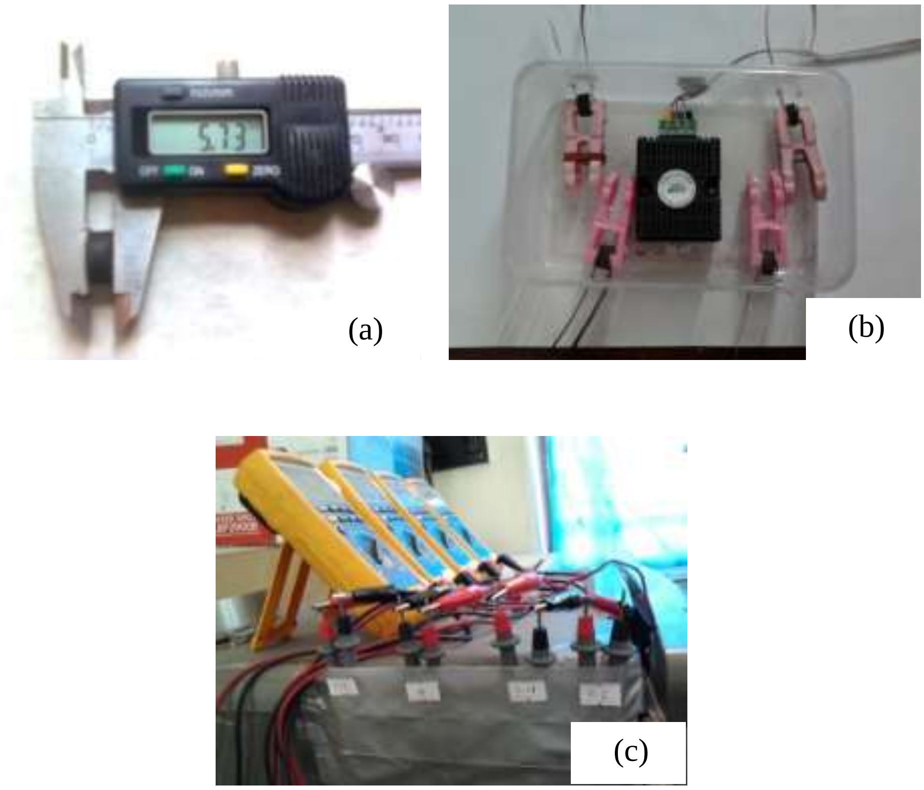

Figure (2) Photographs of the (a) thickness measurement of $Co_{0.5}Zn_{0.5}Fe_2O_4$ pellet, (b) sample and sensor in the same condition, (c) the wiring connection of sample and multimeter

Table (1) Thickness of the $Co_{0.5-x}Ni_xZn_{0.5}Fe_2O_4$ (where x = 0.0, 0.1, 0.2 and 0.3) samples

Sr. No.	Sample (Contents x of Ni)	Thickness (mm)
1	0.0	5.73
2	0.1	5.74
3	0.2	5.74
4	0.3	5.73

Results and Discussion

The spinel ferrites are chemically stable, have porous structure and resistive type. This type of property of the materials can be used as humidity sensors applications. In the present work, the humidity sensitive electrical resistances R_H of the samples in the relative humidity range of 36 RH% - 98 RH% with the step of 1 RH% are shown in Figure 3(a-d). It can be seen that the slopes of the curves are found to be two portions and these portions with corresponding humidity ranges are also shown in Figure 4(a-h). The slope of the R_H-RH% curve can be taken as the sensitivity of the sample. In this work, the obtained sensitivities are listed in Table (2).

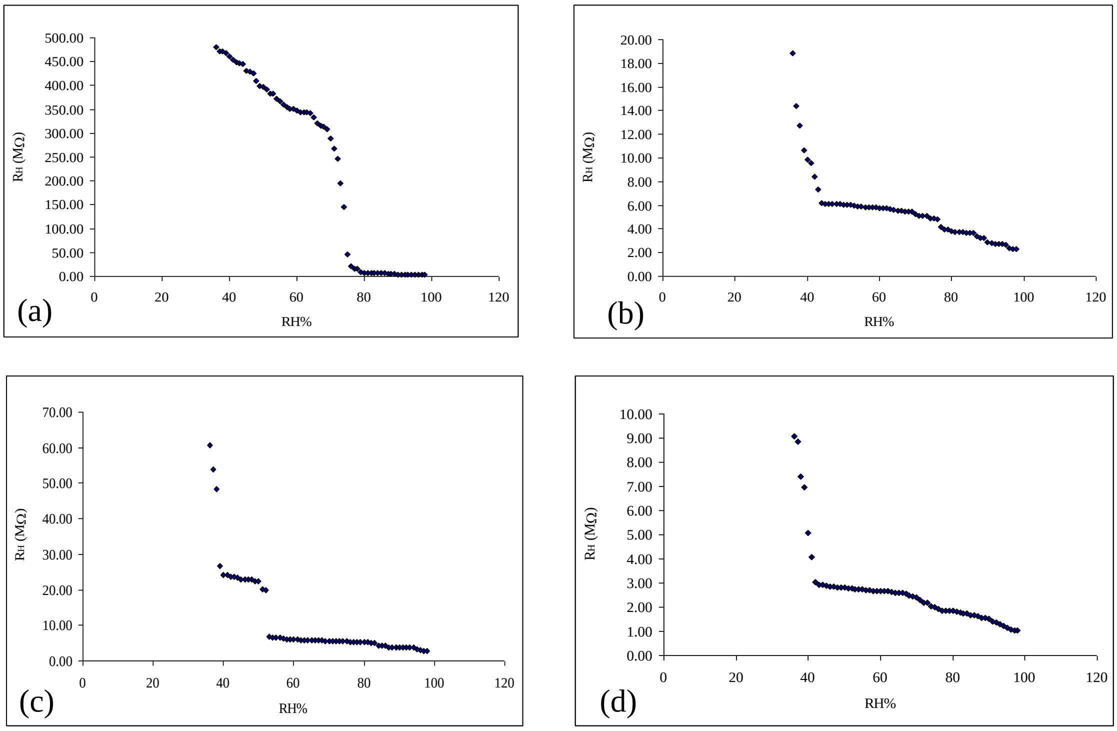

Figure (3) Humidity sensitive electrical resistances R_H of $Co_{0.5-x}Ni_xZn_{0.5}Fe_2O_4$ (a) x = 0.0, (b) x =0.1, (c) x = 0.2 and (d) x = 0.3

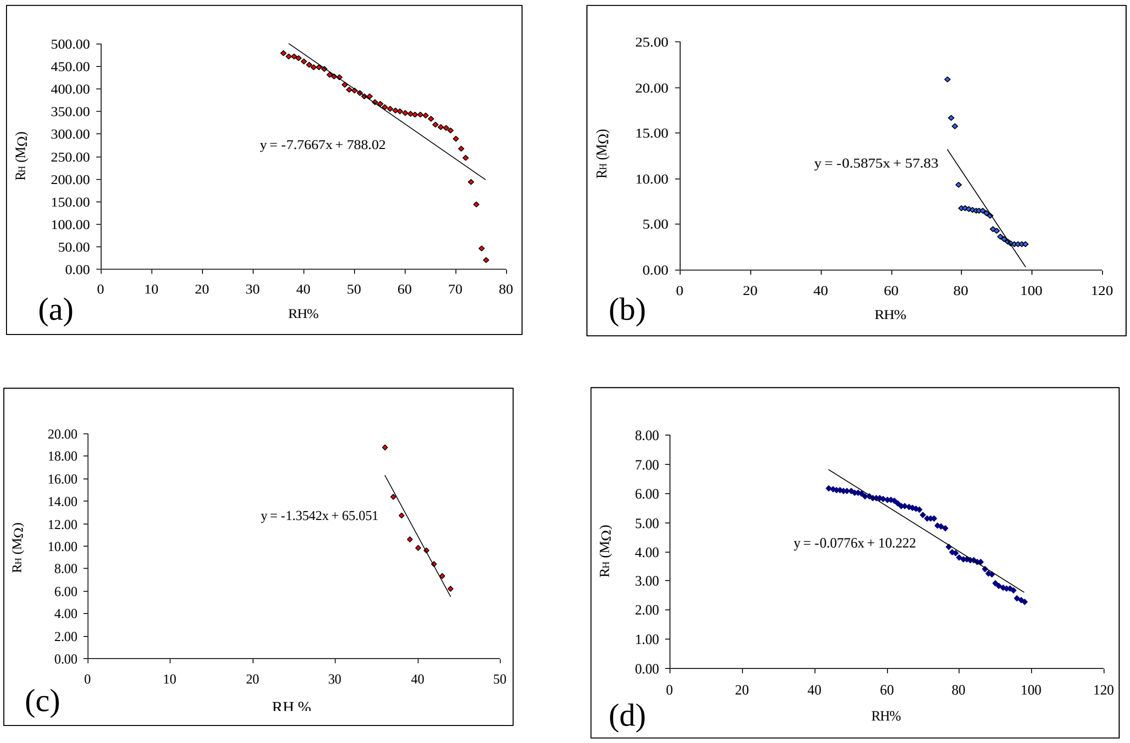

Figure (4) Humidity sensitive electrical resistances R_H of $Co_{0.5x}Ni_xZn_{0.5}Fe_2O_4$ for x = 0.1 in the relative humidity ranges of (a) 36 RH% – 76 RH%, (b) 76 RH% – 98 RH%, (c) 36 RH% – 44 RH%, (d) 44 RH% – 98 RH%

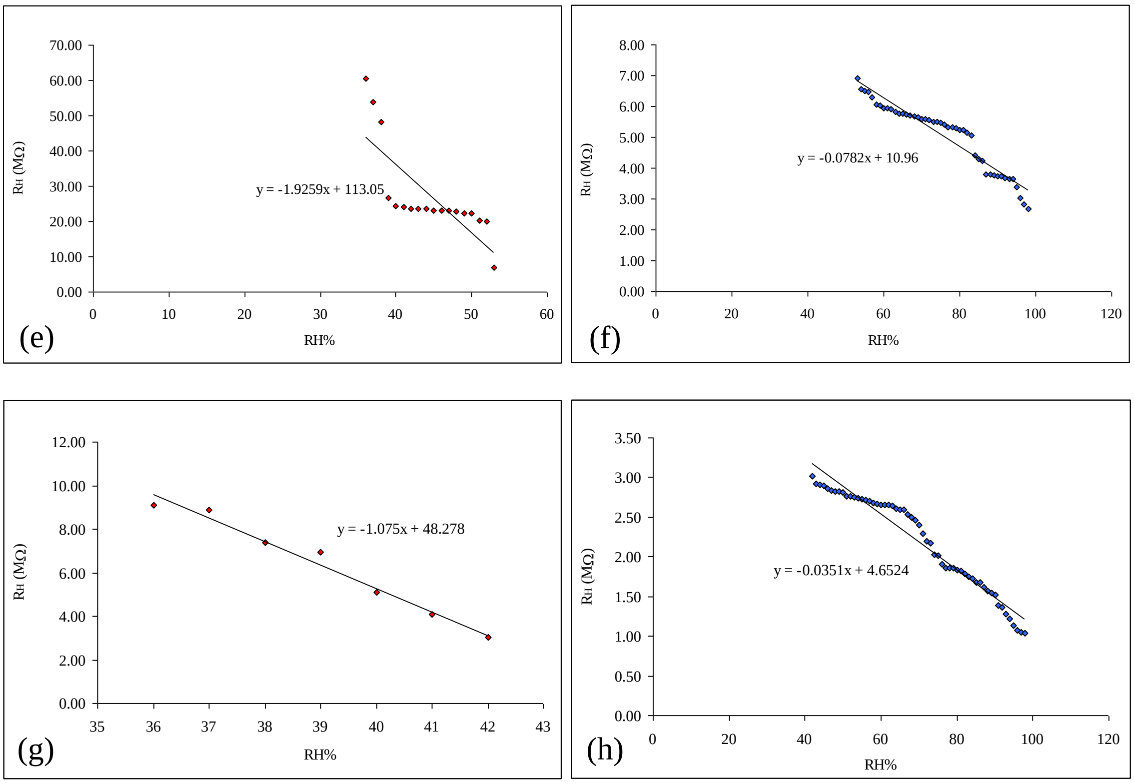

Figure (4) Humidity sensitive electrical resistances R_H of $Co_{0.5x}Ni_xZn_{0.5}Fe_2O_4$ for x = 0.3 in the relative humidity ranges of (e) 36 RH%-53 RH%, (f) 53 RH%-98 RH%, (g) 36 RH%-42 RH%, (h) 42 RH%-98 RH%

Figure 5(a - d) show the humidity sensitive dc voltages and capacitances of the samples. It was found that the electrical properties of dc voltages and capacitances of the samples increased with increase in relative humidity. As shown in figures, the observed characteristic curves of the x = 0.0 and x = 0.2 are found to be the same in patterns. Also, x = 0.1 and x = 0.3 are the same in pattern.

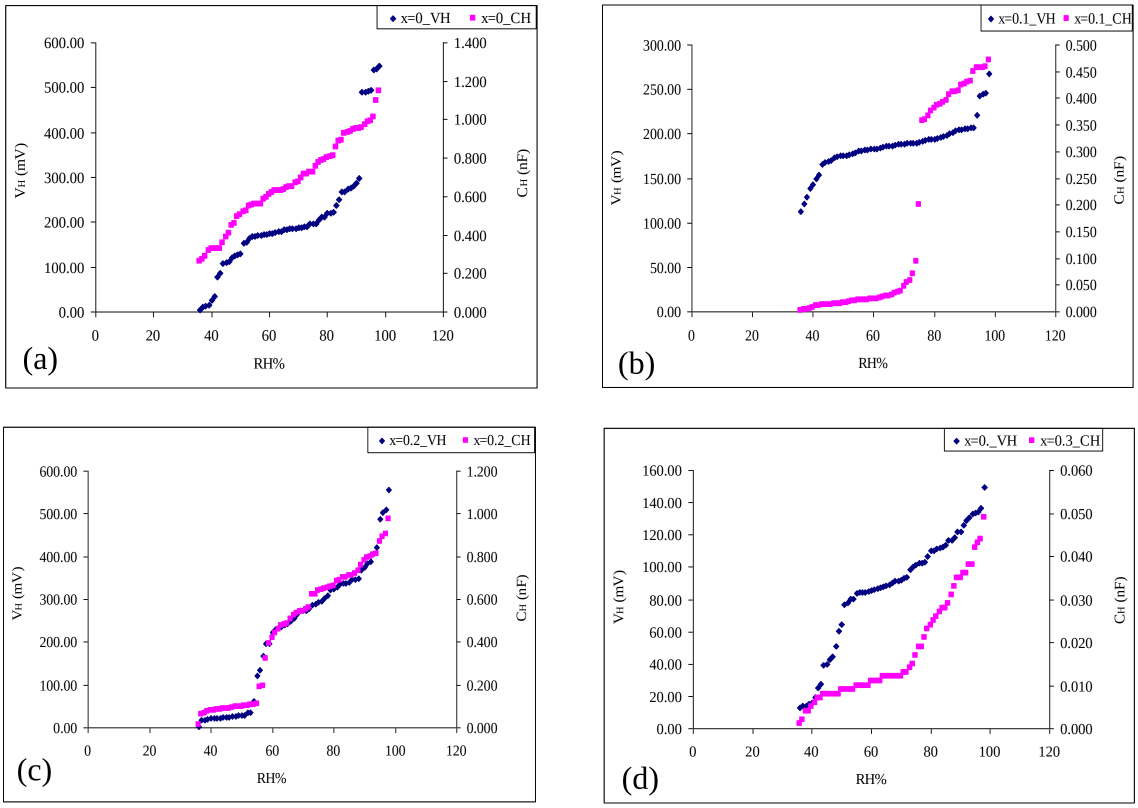

Figure (5) Plots of the variations of dc voltage V_H and capacitance C_H with relative humidity RH% of $Co_{0.5-x}Ni_xZn_{0.5}Fe_2O_4$ (a) x = 0.0, (b) x = 0.1, (c) x = 0.2, (d) x = 0.3

Table (2) Sensitivities of the $Co_{0.5-x}Ni_xZn_{0.5}Fe_2O_4$ (where x = 0.0, 0.1, 0.2, 0.3) samples

Sr. No.	Sample (Contents x of Ni)	Humidity range (RH%)	Sensitivity (MΩ/RH%)
1	x = 0.0	36 – 76 76 – 98	7.7667 0.5875
2	x = 0.1	36 – 44 44 – 98	1.3542 0.0776
3	x = 0.2	36 – 53 53 – 98	1.9259 0.0782
4	x = 0.3	36 – 42 42 – 98	1.0750 0.0351

Conclusion

Nickel substituted Cobalt-Zinc ferrites samples with the chemical compositions of $Co_{0.5-x}Ni_xZn_{0.5}Fe_2O_4$ were prepared by co-precipitation method. It has been proved that co-precipitation method is a versatile and effective technique to prepare spinel type ferrites. From the humidity sensitive electrical properties measurements, obviously it is found that $Co_{0.5-x}Ni_xZn_{0.5}Fe_2O_4$ (where x = 0.0) or $Co_{0.5}Zn_{0.5}Fe_2O_4$ (Co-Zn mixed ferrite) is the most suitable humidity sensor among the candidate materials in the humidity range 36 RH% – 76

RH%. The graphs of dc voltage, V_H against the applied increasing relative humidity, RH% and capacitance against the applied increasing relative humidity, RH% were increased.

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