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Comparative Study of Ferrite Based Humidity Sensor for Smart Sensor Module Design

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ABSTRACT

Spinel ferrites, the magnetic semiconductor, are exhibiting remarkable surface phenomenon, wherein the process of adsorption is most significant. Humidity sensing is the realization of adsorption mechanism. Therefore, ferrites would be suitable for humidity sensing applications. Considering this fact into account, the compositions of polycrystalline Ni-Zn and Mn-Zn ferrites have been prepared by chemical route and characterized by standards tools like X-ray powder diffraction and FTIR spectroscopy. From the results of X-ray diffraction investigation, formation of single phase compositions is confirmed. The average particle size obtained by using Scherrer method is within the range from 40 nm to 78 nm. The existence of the nanoparticles results into increase of the surface area required to favour adsorption mechanism. FTIR spectrographic studies, reveals the existence of various modes of the lattice vibration. The significant absorption bands were observed for higher range of frequencies, which are attributed to the modes of vibration of water molecules present in the sample. This is attributed to the hygroscopic nature of the ferrites. Therefore, it can be used for development of the humidity sensor. The relative humidity sensor is designed by depositing thick film of the materials under investigation on ceramic substrate. Electrical resistance of the sensor (R_H) is measured for variable relative humidity and it shows decreasing trend with increase in the relative humidity. The relative deviation in resistance, '□R' is also estimated with applied humidity. It is found that, the DR increases with humidity. The results reveal the suitability of materials for sensor based application. The sensitivities of the compositions are also determined and results obtained are attributed to the nanostructure of the compositions. On investigation of results obtained, is confirmed that, the sensor developed on Ni-Zn ferrites are most suitable for deployment of the same to design the Smart Sensor Module (SSM). The timing response data reveal the fact that, present sensor are fast sensor, which help to enhance the features of SSM.

Keywords: the magnetic semiconductor, adsorption, X-ray powder diffraction, relative deviation, SSM

INTRODUCTION

Precise measurement of humidity is need of hour for various applications, such as agricultural sector, chemical and medical industries, paper and sugar industries, food processing and preservation plants etc. Humidity is the concentration of water vapors in the air. Therefore, humidity measurement and control of polyhouse environment for precision agriculture, food storage and preservation plant, paper manufacturing industries is very important [1]. To realize the preciseness in the measurement, the humidity sensor should be of prominent features. The sensing material and sensing principle play a key role on the specification of the sensor. The state- of-art of recent technologies is to develop smart sensor module, wherein the features of the devices are optimized by using electronic technologies to cater the need of smart sensor module [2,3]. In the present research work the humidity sensing materials of promising features is synthesize and comparative study of these material and by deploying suitable composition to designing of electronic system to realize precise measurement of the humidity of the desired environment [4]. Therefore, based on polycrystalline $Ni_xZn_{1-x}Fe_2O_4$ and $Mn_xZn_{1-x}Fe_2O_4$ nanoferrite materials, synthesized in the laboratory, the humidity sensors are fabricated and investigated for their performance.

METHODOLOGY

The compositions of polycrystalline spinel ferrite with chemical formula $Ni_xZn_{1-x}Fe_2O_4$ and $Mn_xZn_{1-x}Fe_2O_4$ (x = 0.2, 0.4, 0.6 and 0.8) have been prepared by using coprecipitation method. Fine powders of these composi-tions were subjected to X-ray diffraction and FTIR Spectroscopy is employed for confirmation of formation of spinel ferrites. To keep pace with the objectives, the investigation of electrical properties and designing of smart sensor module, ensuring an embedded technology, the compositions of the ferrites under investigation are shaped as per the requirement. Due to micro structural properties of polycrystalline spinel ferrites are most suitable for electro-chemical sensor applications [5]. On literature survey, it is found that, the polycrystalline spinel ferrite materials are mostly suitable for humidity sensing application due to its humidity dependent electrical conduction mechanism. The humidity dependent electrical conduction mechanism described in patil et al. [6]. The sensor under investigation has prepared on rectangular film and employed for investigation of humidity dependent electrical properties of the compositions $Ni_xZn_{1-x}Fe_2O_4$ and $Mn_xZn_{1-x}Fe_2O_4$. Experimental arrangement for measurement of humidity dependent characteristics of the composition is shown in figure 1. The electrical resistance (RH), of the composition were measured with variable relative humidity.

Figure 1: Experimental arrangement for measurement of humidity dependent characteristics of the composition under investigation.

RESULT AND DISCUSSION

The compositions, $Ni_xZn_{1-x}Fe_2O_4$ and $Mn_xZn_{1-x}Fe_2O_4$ (x= 0.20, 0.40, 0.60 and 0.80) of ferrites are characterize by X-ray powder diffraction. The obtained diffractograms are depicted in Figure 2 typically for composition of $Ni_xZn_{1-x}Fe_2O_4$ and $Mn_xZn_{1-x}Fe_2O_4$ (x= 0.40, 0.60). The diffractograms shows well defined reflections which supports the formation of single phase spinel ferrite. [7]. In ferrites, humidity dependent electrical conduction depends upon the surface phenomenon. Therefore, the porosity and grain size plays vital role on humidity sensing property. Deploying the scherrer relation particle size for each reflection is calculated. The average particle size varies from 40 to 80 nm. [36,37]. The compositions are also subjected to FTIR spectroscopy for confirmation of feerite material.

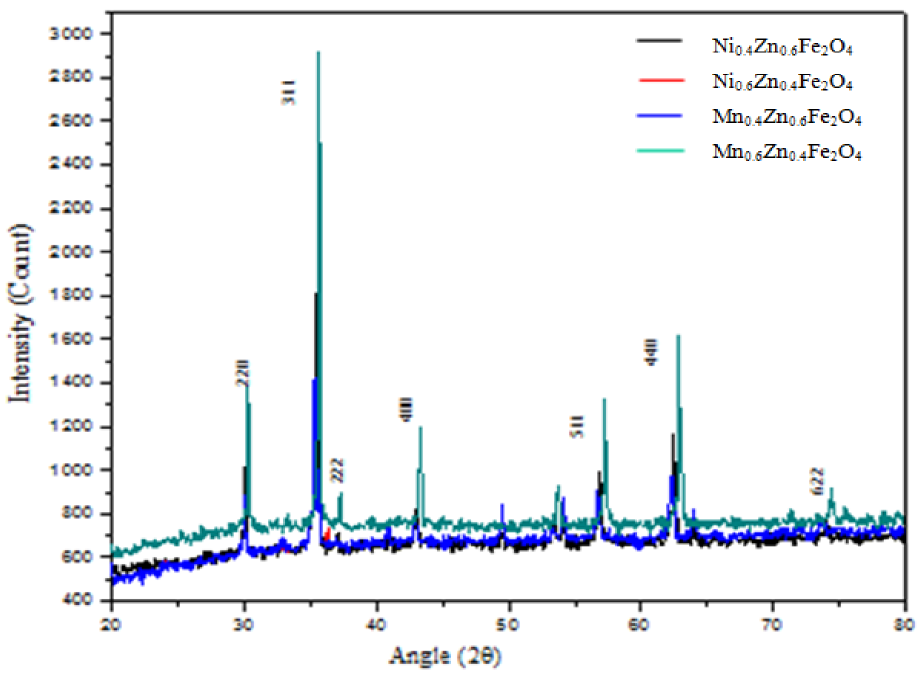
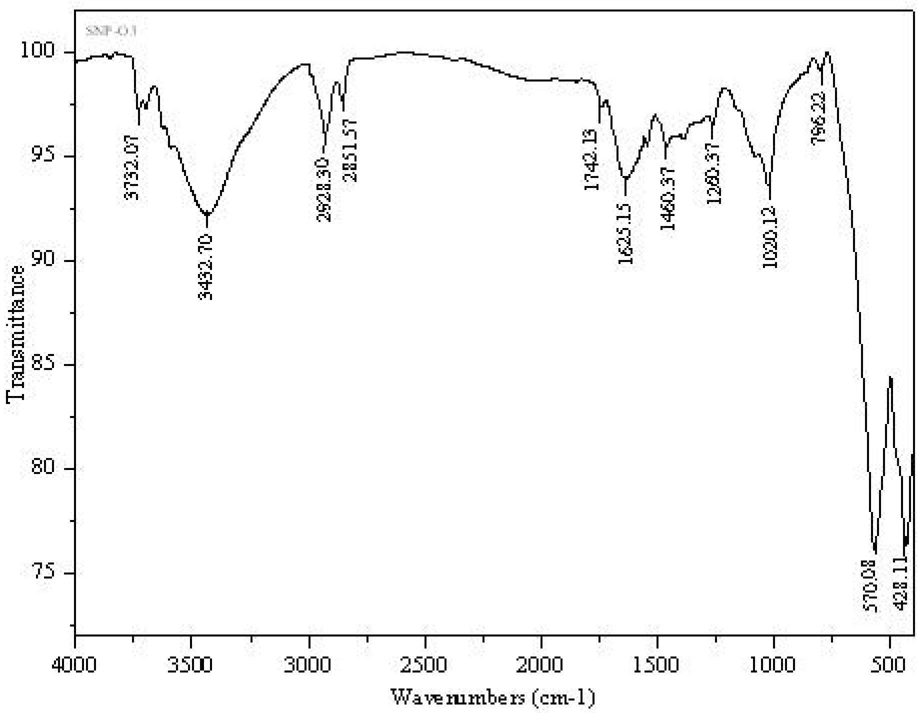


Figure 2: X-ray diffraction for composition of $Ni_xZn_{1-x}Fe_2O_4$ and $Mn_xZn_{1-x}Fe_2O_4$ (x= 0.40, 0.60)



Figures 3: IR absorption spectra of the composition $Ni_xZn_{1-x}Fe_2O_4$ (x=0.60)

Figure 3 shows IR absorption spectra of the NiZn composition. It provides informa-tion regarding functional group and their linkages [10]. The absorption band observed at specific limit reveal the formation of spinel ferrite and hydroscopic nature of ferrite material. Therefore, this results supports the polycrystalline ferrite compositions can suitably used for humidity sensing application.

HUMIDITY SENSITIVE ELECTRICAL PROPERTIES OF THE SENSING ELEMENT

The Humidity dependent resistance 'R_H', of the thick film sensors, deposited on ceramic substrate is measured with variable relative humidity from 30 % RH to 95%RH. The temperature is controlled at 35 ^{0}C. To interpret humidity dependent conductivity mechanism, the values of resistance 'R_H' in $M\Omega$ are plotted against applied relative humidity (%RH) and shown in figure 4. From these graphs, it is found that the resistance of the compositions under investigation exponentially decreases with increase in the relative humidity. Such nature of curve of R_H against -H is reported by various researchers for ferrites compositions [6, 11-14]. On inspection it is found that, at 30% RH humidity the resistances of the sensing element for x= 0.20, 0.40, 0.60 and 0.80 are substantially high. As shown in figure 4, the R_H for x = 0.60 exhibit sudden drop at and above 60 %RH. This may be due to existence of capillary condensation of water. Within this region conduction may be due to both proton hopping and capillary condensation of water molecules.

The Relative Deviation in the Resistance (RDR) is obtained from equation

$$\Delta R_H = \frac{R_{1H} - R_H}{R_{1H}} \ x\ 100\%$$

and plotted against relative humidity from 30%RH to 95%RH. The graphs of RDR against RH for all compositions are shown in figure 5. On observation of the figure 5, it is noticed that, the values of RDR (%) increases with increase in the relative humidity. Within the range of investigation, the variation in RDR is wide (up to 80% to the initial value) for samples except x = 0.40. For x = 0.40 the deviation is very narrow and linear. This may be due to the resistance of the sensor observed at ambient conditions. The RDR for sensing elements developed by using MnZn ferrites for x = 0.60. This may causes to increase the sensitivity of the sensor. However, the resistances of these sensors are very high and therefore difficult to ensure the interfacing.

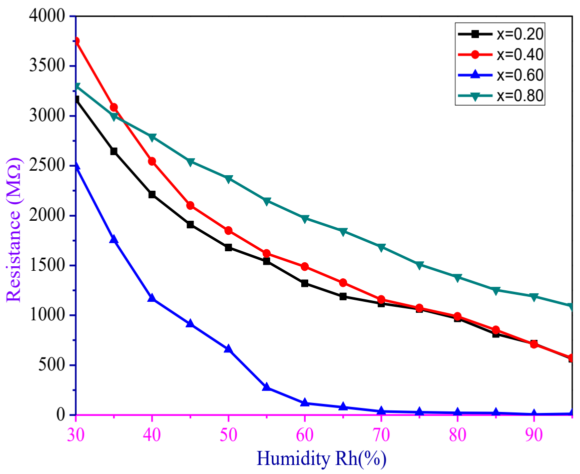


Figure 4

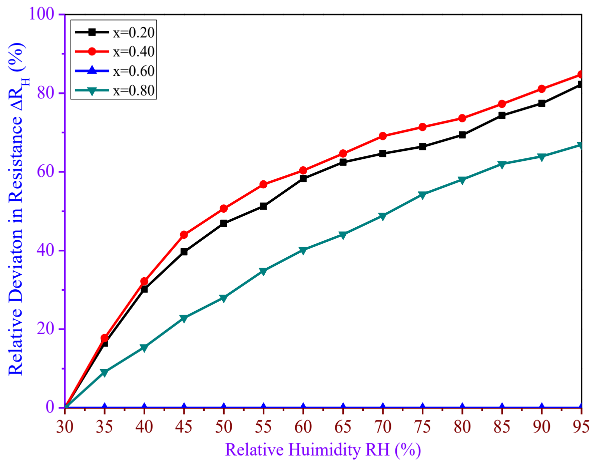
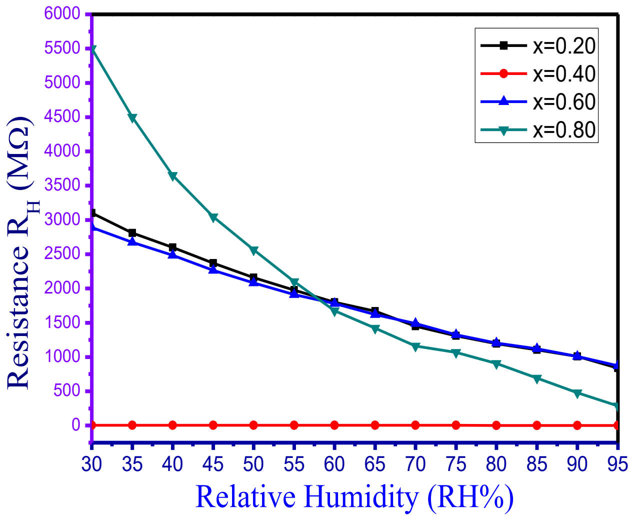


Figure 5

Figure 4: Graph of Resistance (R_H) against applied relative humidity (%RH) for thick film of compositions of $Mn_xZn_{1-x}Fe_2O_4$nanoferrites deposited on ceramic substrate

Figure 5: Graph of Relative Deviation in Resistance (RDR) against applied relative humidity (%RH) for thick film of compositions of $Mn_xZn_{1-x}Fe_2O_4$nanoferrites deposited on ceramic substrate.



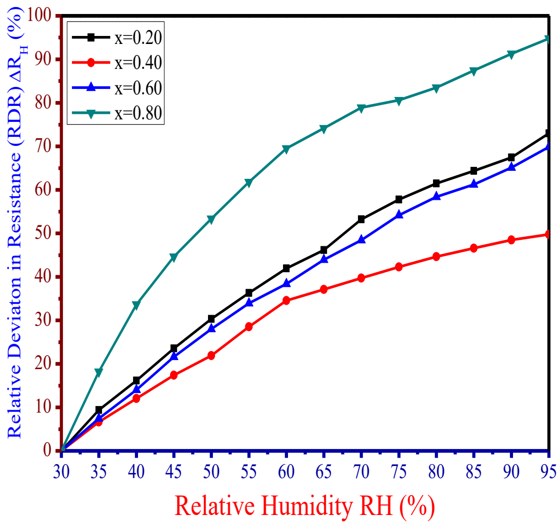


Figure 6 **Figure 7**

Figure 6: Graph of Resistance (R_H) against applied relative humidity (%RH) for thick film of compositions of $Ni_xZn_{1-x}Fe_2O_4$ nanoferrites deposited on ceramic substrate

Figure 7: Graph of Relative Deviation in Resistance (RDR) against applied relative humidity (%RH) for thick film of compositions of $NI_xZn_{1-x}Fe_2O_4$ nanoferrites deposited on ceramic substrate.

Further, the thick film sensors (TFS) are developed by depositing thick film of compositions of $Ni_xZn_{1-x}Fe_2O_4$ nanoferrites on ceramic substrates and deployed for investigation of their humidity dependent characteristics. The values of R_H, in M□, are plotted against RH (%) and presented in the figure 6. Moreover, the values of relative deviation in resistance (RDR), in %, is calculated for all compositions by using expression 1 and plotted against relative humidity (%RH). The graphs of RDR against RH are presented in figure 7. From inspection of figure 6, it is found that, the RDR values of the sensing element, developed by employing compositions of x = 0.20 and 0.60, show almost linear behavior for entire range of investigation. This supports the applicability of the present sensor for development of sensor unit. This nature of the graph simplifies the process of calibration, for designing of smart sensor module. The Humidity sensitivities, S_H, are obtained from R_H data for various ranges relative humidity for both series and presented in the table 1. The table reveals the compositional dependence of the sensitivity. The value can be attributed to the resistance level at ambient conditions.

Table 1 : Humidity sensitivity S_H for different ranges of humidity for the samples of $MnZn_{1-x}Fe_2O_4$ ferrites

Humidity Range (%RH)	**Humidity Sensitivity (□R/□H) (M□/%RH) for the composition for**			
	x = 0.20	**x = 0.40**	**x = 0.60**	**x = 0.80**
30-40	87.00	108.00	117.60	41.40
40-50	46.00	50.00	50.80	34.00
50-60	44.40	26.60	31.20	35.00
60-70	14.00	33.40	8.40	31.60
70-80	18.80	16.80	1.08	25.20
80-90	19.40	28.60	2.80	12.60

Table 2: Humidity sensitivity S_H for different ranges of humidity for the samples of $Ni_xZn_{1-x}Fe_2O_4$ ferrites

Humidity Range (%RH)	Humidity Sensitivity (□R/□H) (M□/%RH) for the composition for			
	x = 0.20	**x = 0.40**	**x = 0.60**	**x = 0.80**
30-40	42.00	0.050	38.00	170.00
40-50	42.00	0.042	37.00	96.00
50-60	35.00	0.056	26.00	85.00
60-70	44.00	0.024	26.00	51.80
70-80	23.00	0.022	24.40	32.00
80-90	19.20	0.018	22.40	42.60

Table 3: Response time (T_{RES}) and Recovery time (T_{REC}) for sensing elements of ferrite compositions for 90 %RH.

Conc. x	$Mn_xZn_{1-x}Fe_2O_4$		$Ni_xZn_{1-x}Fe_2O_4$	
	Response Time (T_{RES}) in Sec	**Recovery Time (T_{REC}) in Sec**	**Response Time (T_{RES}) in Sec**	**Recovery Time (T_{REC}) in Sec**
0.20	10	5	10	5
0.40	11	8	19	9
0.60	12	9	10	7
0.80	9	7	14	6

On inspection of table 1, it is found that, humidity sensitivity of the compositions for x = 0.20 and 0.40 is substantially high for MnZn composition and x= 0.20 and 0.80 of NiZn compositions. The sensitivity of sensing element for x = 0.40 is less. However, the ambient resistance of the sample is less. This data about humidity sensitivity of the sensing element and resistance at ambient conditions are most useful for designing of an analog part of the electronic circuit. Therefore, NiZn is highly suitable for interfacing to the analog circuit, wherein impedance matching will be realized [15].

TIMING CHARACTERISTICS

After investigation of humidity dependent resistive property of sensing element, its timing parameters studied. The response time (T_{RES}) and recovery time (T_{REC}) measure and depicted in table. [16]. The time response of the samples to RH% was determined by inserting the samples into the humidity chamber at the different settings and the time required for the sensing element to sense the correct RH% is recorded and presents the values of timing parameters in table 3.

CONCLUSION

On investigation of results obtained, it is confirmed that, the composition under investigation were successfully synthesized and the sensor developed on ceramic substrate are most suitable for deployment of the same to design the Smart Sensor Module. Emphasizing adsorption and absorption sensitive electrical properties of polycrystalline ferrites, the electrical resistance (RH) of the compositions $Ni_xZn_{1-x}Fe_2O_4$ and $Mn_xZn_{1-x}Fe_2O_4$ nanoferrites have been investigated. The sensing element is fabricated by developing thick film of the materials on the substrate. The compositions show decrease in the resistance with increase in the relative humidity. The natures of the graphs are attributed to existence of conducting mechanism. The relative deviation in the resistance values and humidity sensitivity are also studied. The timing response data reveal the fact that, present sensor are fast sensor, which help to enhance the features of SSM. For selection of composition for SSM ambient condition resistance, response time were consider. From the result of investigation it can be conclude that the composition x=0.40, 0.60 for NiZn and x=0.60, 0.80 for MnZn under investigation are most suitable for sensor based applications.

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