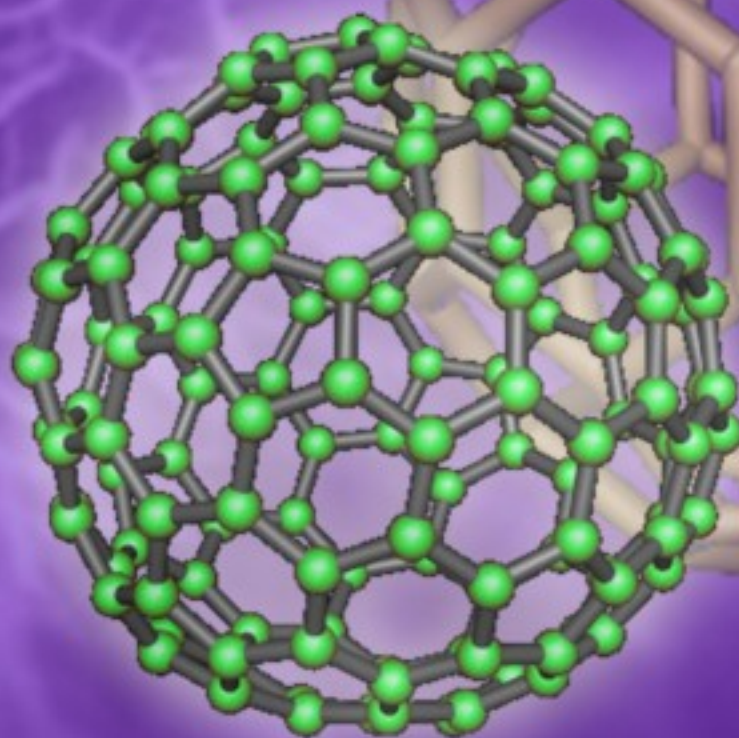
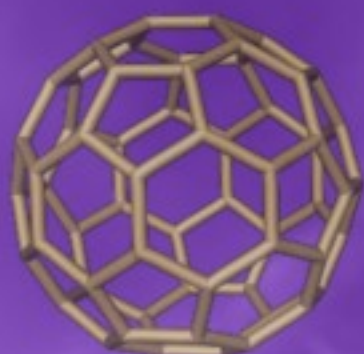


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Structural Properties of Nanosized NiFe₂O₄ for LPG Sensor

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Abstract: Nanocrystalline NiFe₂O₄ has been synthesized by sol-gel citrate method. The synthesized powder was characterized by X-ray diffraction (XRD) and Transmission electron microscopy (TEM). As found from the XRD line broadening, the crystallite size of the powder was found to be 40 nm. The gas sensing properties were studied for reducing gases such as LPG, CH₄, CO and NH₃. It was observed that the nanosized NiFe₂O₄ shows high sensitivity for LPG at an operating temperature 300 °C. Pd incorporation in NiFe₂O₄ results in a decrease in operating temperature by 100 °C and improves the sensing characteristics in terms of response time. *Copyright © 2009 IFSA.*

Keywords: NiFe₂O₄, Gas sensor, Sensitivity, Selectivity

1. 1. Introduction

Recently, due to increase in the usage of liquefied petroleum gas [LPG], the frequency of accidental explosions due to leakage has increased. Therefore, the ability to monitor and precisely measure leakages of explosive gases is crucial in preventing the occurrence of such accidents. Accordingly, the development of sensors and systems that can selectively detect and determine various kinds and quantities of combustible gases within the ranges of explosion limits are required. In recent years, nanosized materials have been widely studied as possible candidates for the fabrication of gas sensors. A large number of metal oxides such as ZnO, SnO₂, WO₃ and mixed oxides, ZnGa₂O₄ have shown sensitivity to certain gases. Spinel compounds have also been proved as important oxides in gas sensors. Spinel structure, generally denoted by the formula AB₂O₄ contains two cation occupancy sites: the A sites have a tetrahedral coordination by oxygen, while the B sites are octahedrally coordinated.

The fraction of tetrahedral A sites and octahedral B sites are strongly influenced by the preparation methodology [1]. Therefore, the synthesis of NiFe₂O₄ is still worth trying.

In recent years the ferrites have demonstrated to be good materials for gas sensing applications. Nickel ferrite has been used as an n-type semiconductor for the detection of different gases [2]. This material is a technological important material and widely used in various fields of industry including magnetic materials, gas sensors, catalysts and medicines [3, 4].

There are several methods that can be used for the production of sensor materials with sputtering, sol-gel synthesis and thermal evaporation being a few examples [5, 6]. Very recently, the sol-gel technique [7-9] is one of the most used ones, owing to its economic and high degree of compositional control. In addition, the sol-gel method requires neither extremely high processing temperature nor sophisticated process. In this study, sol-gel technique was used to obtain nanosized NiFe₂O₄ powder.

Many approaches have been made to modify the sensing properties of these semiconductor oxide gas sensors in order to achieve high sensitivity and selectivity. In this direction different approaches are adopted such as additives, physical or chemical filters, or operating temperature, etc. Noble metals (Ag, Pd, Au) are well known for enhancing the rate of response and raising selectivity to a particular gas. The doping is generally based on the selection of most effective catalysts, which modulate specific chemical reaction on the semiconductor sensor surface. The noble metals, well known as active catalysts, have been confirmed to possess the promoting effects on many semiconductor gas sensors [10–13].

We experimentally illustrate the way one can achieve the nanosized material and the parameters that are important for their structural and gas sensing properties. This work was aimed at preparing n-type spinel NiFe₂O₄ by sol-gel citrate method. The structural characterization was carried out by means of X-ray diffraction (XRD) and Transmission electron microscopy (TEM). XRD pattern were recorded by using CuK_α radiation.

2. 2. Experimental Details

Nanocrystalline NiFe₂O₄ powder was synthesized by using sol-gel citrate method. A stoichiometric mixture of nitrates such as Ferric nitrate [Fe(NO₃)₃·9H₂O], Nickel nitrate [Ni(NO₃)₂·6H₂O] was mixed with citric acid and ethylene glycol. The resultant mixture was stirred magnetically at 80 °C for 2 h to get homogeneous mixture. The solution was further heated in pressure vessel at about 130 °C for 12 h and subsequently kept at 350 °C for 3 h. The dried powder then calcined in the range of 450-650 °C in order to improve the crystallinity of powder. Different noble metals such as Pd, Ag and Au were incorporated in the NiFe₂O₄. Appropriate quantities of corresponding chlorides of Pd, Ag and Au solution were added to the nitrating mixture.

For gas sensing properties, the calcined powder was then mixed with 2 % PVA (polyvinyl alcohol) as a binder and 5 % ethanol as a solvent, the resulting paste was coated onto an Al₂O₃ tube on which two platinum wires had been installed at each end. The Al₂O₃ tube was about 8 mm in length, 2 mm in external diameter and 1.6 mm in internal diameter. A small Ni-Cr alloy coil was placed through the tube as a heater, which provided operating temperatures at 50-350 °C. The temperature was controlled by adjusting the heating power.

Finally, the sensor was sintered at 600 °C for 1 h so that the PVA decomposes and strength of the element markedly increases. The different test gases are injected into the specimen chamber through an inlet. The sensing performance of the sensors was examined using the 'static gas sensing system'.

The output voltage across the sensor element at a 10 V input voltage is taken to determine the resistance of the element.

The gas sensitivity (S) is defined as the ratio of the change of resistance in presence of gas (R_g) to that in air (R_a) [14].

$$S = (R_a - R_g)/R_a = \Delta R/R_a \quad (1)$$

In order to calculate the sensitivity, the electrical resistance of the element was measured in presence of 5000 ppm of LPG in dry air. The synthesized samples were characterized by X-ray diffraction (XRD) using a Siemens D5000 diffractometer. The X-ray diffraction data were recorded by using Cu K_α radiation (1.5406 \AA). The intensity data were collected over a 2θ range of $10\text{--}70^\circ$. The average crystallite size of the samples was estimated with the help of Scherrer equation using the diffraction intensity of all prominent lines. Transmission electron microscopy (TEM) examination of synthesized powder was performed using an H-800 electron microscope.

3. Results and Discussion

The synthesized samples were characterized by X-ray diffraction. Fig. 1 shows the X-ray diffraction (XRD) for NiFe_2O_4 prepared by sol-gel citrate method calcined at 550°C for 6 h. The peaks belong to the spinel ferrite. The XRD pattern of the synthesized NiFe_2O_4 material was found to be similar as reported in the JCPDS (Card no:-74-2081) [3]. The broadening of different peaks indicates that the particles are in nanometer scale. Their average crystallite size of the samples was estimated with the help of Debye-Scherrer formula and it was found to be 40 nm.

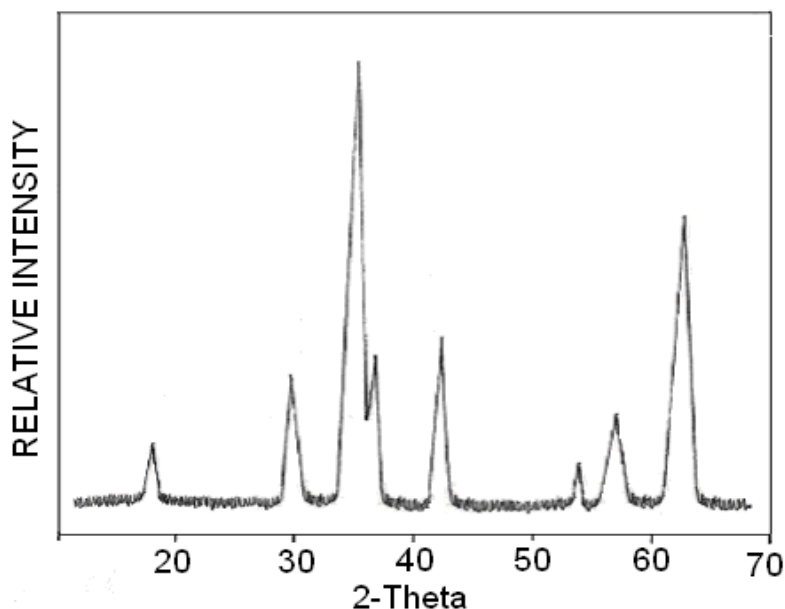


Fig. 1. X-ray diffraction of NiFe_2O_4 calcined at 550°C for 6 h.

Fig. 2 shows TEM image of NiFe_2O_4 calcined at 550°C for 6 h. The morphology of the particles was almost spherical. The particle size was found to be 40 nm. The results are in good agreement with those calculated from XRD.

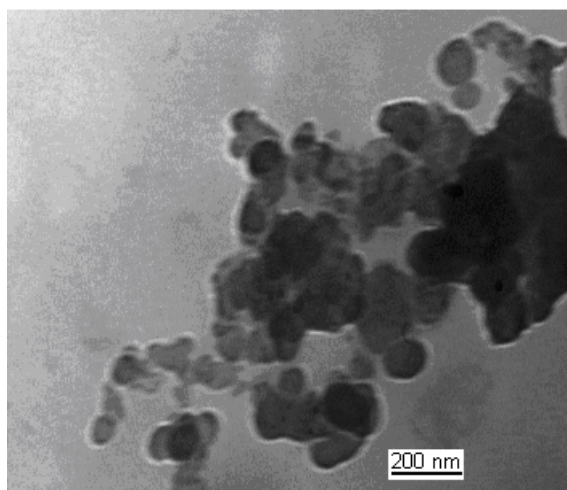


Fig. 2. TEM image of NiFe₂O₄, calcined at 550⁰C for 6 h.

Fig. 3 shows the relationship between the operating temperature and the resistance of NiFe₂O₄ sensor in atmosphere. The resistance of NiFe₂O₄ changes greatly with temperature. The resistance was found to be decreased from several hundreds to several MΩ, with increased in operating temperatures from 50 °C to 350 °C.

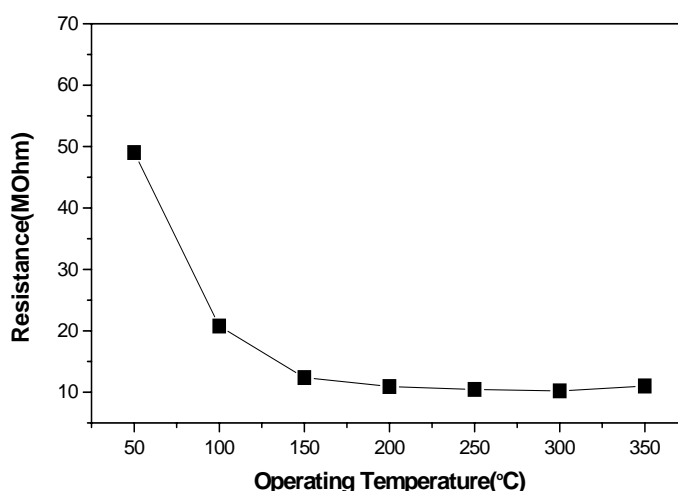


Fig. 3. The resistance- temperature curve of NiFe₂O₄ sensor.

Fig. 4 shows the gas sensing measurement of undoped NiFe₂O₄ at various operating temperature, ranging from 50-350 °C. The elements were tested for reducing gases such as LPG, CO, CH₄ and NH₃ at various operating temperatures. The concentration of the gases has been maintained at 5000 ppm. The sensing characteristics indicate that the element show a high sensitivity to LPG. However, it is observed that the sensitivities to CO, CH₄ and NH₃ gases decrease at elevated temperatures. It reveals that though this material senses all gases at higher temperatures, the sensitivity at about 300°C for LPG is much higher compared to all other gases.

LPG is a mixture of hydrocarbons like *n*-propane and *n*-butane and one of the by products after partial combustion is CO and after complete combustion, it is CO₂ and H₂O. Hence, the sensitivity of the sensor to other reducing gas like CO and CH₄ was also measured as a function of operating temperature.

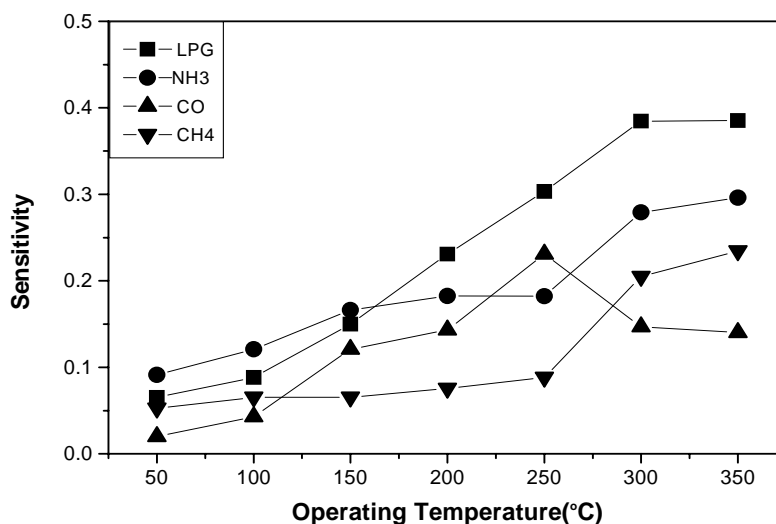


Fig. 4. Sensitivity as a function of operating temperature for undoped NiFe₂O₄ for LPG, NH₃, CO and CH₄.

The sensing properties of the sensors depend on several factors, mainly crystallite size and specific surface area. It was reported that crystallite size decreased as the particle size of the sample decreased [15]. A small particle size, results in a larger specific surface area, which results in greater oxygen adsorption and higher sensitivity [16].

In order to enhance the sensitivity, different noble metals were added. Fig. 5 shows the sensitivity of NiFe₂O₄ samples doped with different noble metals at an operating temperature of 200 °C. The sensitivity was found to be highest for Pd doped NiFe₂O₄ as compare to Au and Ag doped NiFe₂O₄, indicating that the LPG detection was sensitized quite effectively by the addition of Pd.

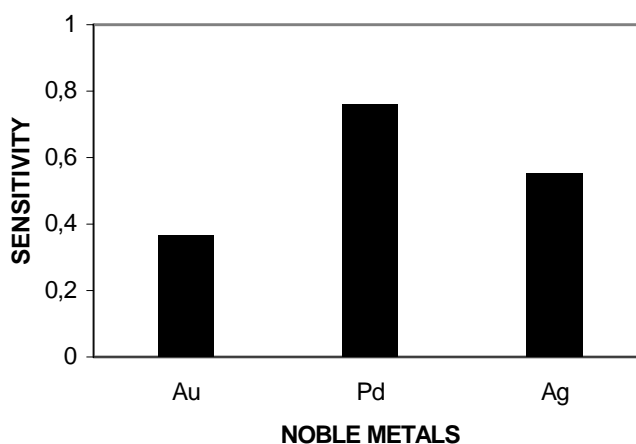


Fig. 5. Sensitivity of NiFe₂O₄ doped with different noble metals for LPG sensor at an operating temperature 200°C.

The increase in sensitivity in NiFe₂O₄ as a function of noble metal additive can be explained on the basis of work-function model (i.e. the minimum energy required to take out electron from the metal surface). When the metal–semiconductor contact is formed, the semiconductor surface is depleted of electrons because of the flow of electrons from semiconductor to metal as a result of the larger work

function of the metal compared to the semiconductor. In case the difference in the work function is larger, i.e. for metals with higher work function, this depletion of electrons is much more pronounced which gives rise to a larger barrier height. This manifests a larger electrical resistance of the sensor material (semiconductor and metal) in air. When exposed to a reducing gas, the change in resistance, because of the decrease in junction barrier height becomes more significant and in effect this increases the value of the gas response [17]. This argument holds true even in the present case and the nanostructuring of the base semiconducting oxide also contributes to a large improvement in the sensitivity. In addition, palladium is known to have a catalytic effect due to its excellent oxidation capability to convert hydrocarbons at lower temperatures [18] making the sensor selective to hydrocarbons. The effect of Pd on the sensitivity for LPG detection was further studied as a function of different wt% of Pd doped NiFe_2O_4 .

The effect of Pd loading on the sensitivity of LPG sensor at an operating temperature of 200 °C is shown in Fig. 6. Quite notably, the gas sensitivity is very sensitive to the Pd doping. The Pd concentrations were varied from 1-2 wt%. It was found that 1.5 wt% Pd doped NiFe_2O_4 has maximum sensitivity to LPG at 200 °C as compare to 1 and 2 wt% Pd doped NiFe_2O_4 .

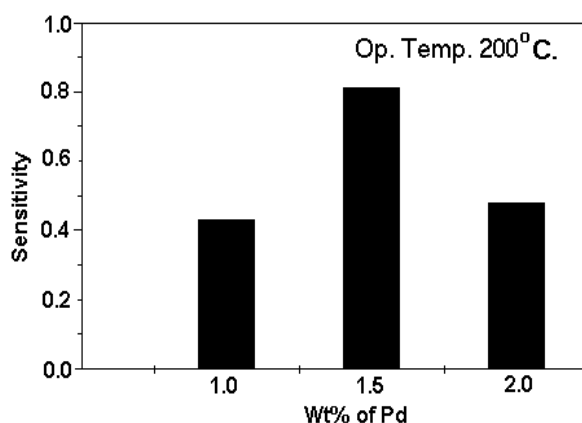


Fig. 6. Sensitivity as a function of different wt% of Pd doped NiFe_2O_4 for LPG sensor calcined at 550 °C.

The NiFe_2O_4 sample doped with Pd shows higher sensitivity than the undoped NiFe_2O_4 sample. The dopant increases the gas sensitivity as it increases the rate of the chemical process leading to a decrease in concentration of the chemisorbed oxygen species on the surface of semiconductor, which may be the dominant reason for the lower operating temperature of the NiFe_2O_4 sensor doped with Pd.

Pd may serve as specific adsorption sites to dissolve O_2 and to adsorb gas molecules to be detected. At appropriate temperature, the test gas is first adsorbed on the surface of the noble metal particles. The gas molecules then spill over or migrate to the semiconductor surface. Therefore, Pd activates LPG to facilitate its catalytic oxidation on the NiFe_2O_4 surface. Fig. 7 shows the cross sensitivity of Pd doped NiFe_2O_4 for LPG, NH_3 , CO and CH_4 as a function of operating temperatures. The Pd doped NiFe_2O_4 thick film sensor shows highest sensitivity for LPG as compared to other gases.

Sensing mechanism of semiconducting gas sensor is based on the surface reactions of semiconducting oxide. In air, molecular oxygen chemisorbed in the form of O_2^- , O^- or O_2^{2-} depending on operating temperature and deplete electron from the surface of these materials, leading to reduction of conductivity. Upon exposure of the material to the reducing gas, the chemisorbed oxygen reacts with the reducing gas and electrons are subsequently reintroduced into the conduction band, leading to enhanced conductivity.

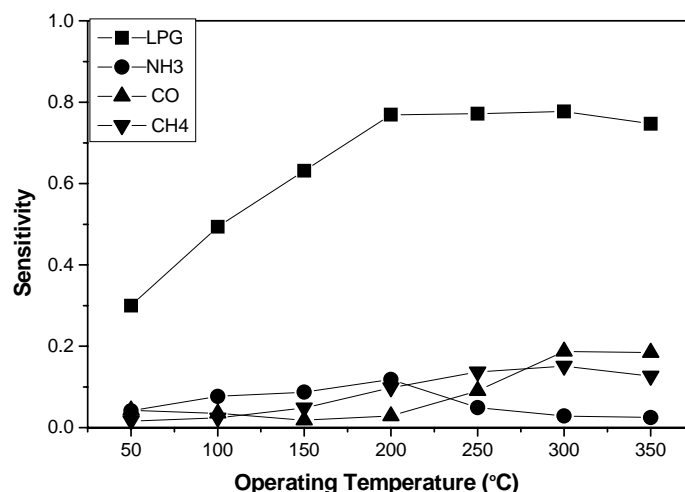
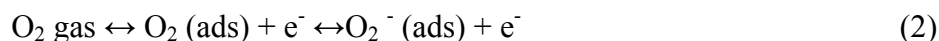


Fig. 7. Cross sensitivity versus operating temperature of 1.5 wt % Pd: NiFe₂O₄ for LPG, NH₃, CO and CH₄.

It is seen that the NiFe₂O₄ nanoparticles exhibit a typical n-type semiconducting behavior, as there is a drop in voltage across the sensor element on exposure to the reducing gas. With the temperature increases, the state of oxygen adsorbed on the surface of NiFe₂O₄ sensor undergoes the following reaction:



The general case of a reducing gas interacting with the adsorbed oxygen at the sensor surface can be explained by the following reaction:



where R is the reducing gas, O⁻ (ads) is the oxygen ion adsorption and e⁻ are freed electrons [19].

Fig. 8 shows the dependence of the sensitivity of 1.5 wt% Pd doped NiFe₂O₄ sensor on the concentration of LPG. This sensor exhibits a good dependence on LPG concentrations. An increase in the gas concentration raises the surface coverage eventually leading to a saturation level. It was found that the sensitivity of 1.5 wt% Pd doped NiFe₂O₄ for LPG starts detecting at 200 ppm and further reaches to saturation level at around 600 ppm.

Response time defined as the time reaching 90 % of final signal, is the important parameter of gas sensors. The response curve of the element towards LPG at an operating temperature 200 °C is shown in Fig. 9. Figure shows that the time taken by the sensor element to reach at maximum sensitivity at an operating temperature of 200 °C is about 50 sec.

The sensitivity of the sensor to LPG was recorded as a function of time. As is shown in Fig. 10, the sensitivity rises i.e.; from 10 days and then remains relatively stable. The initial increase in sensitivity is believed to be caused by activation and redistribution of the impurities. Repeating absorption and desorption processes and redistribution of Pd in the material improves the activation and enhance the absorption and reaction of LPG, causing gradual increase in the sensitivity. The sensitivity becomes more stable after this conditioning process is completed.

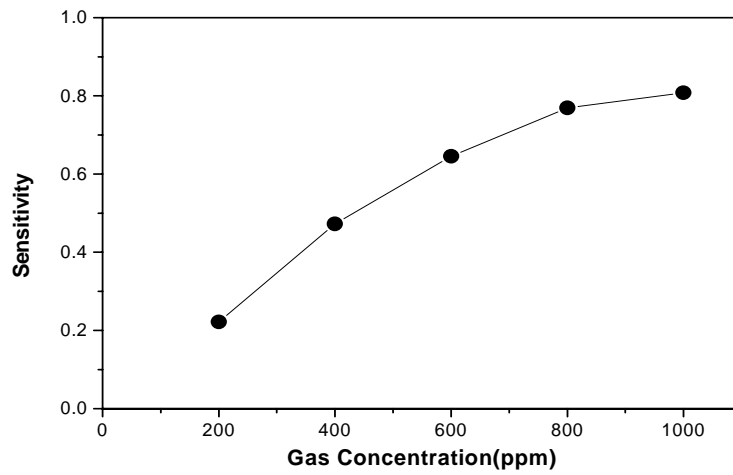


Fig. 8. Variation of sensitivity for 1.5 wt % Pd: NiFe₂O₄ gas sensor as a function of gas concentration for LPG in ppm.

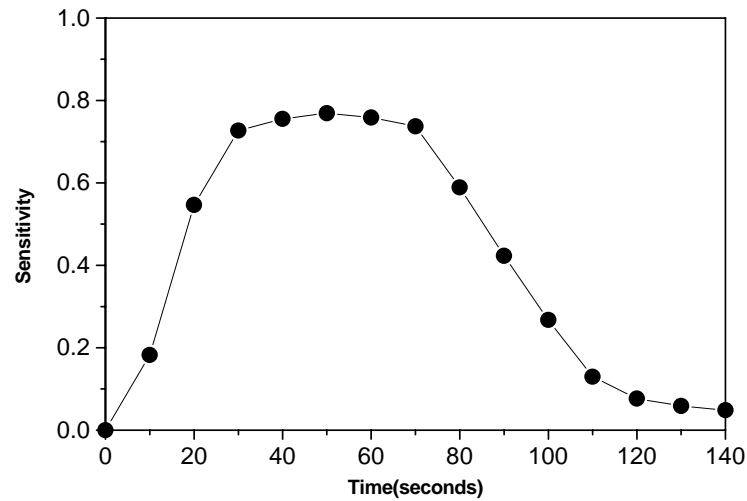


Fig. 9. Response characteristics of 1.5 wt. % Pd: NiFe₂O₄ at 200 °C.

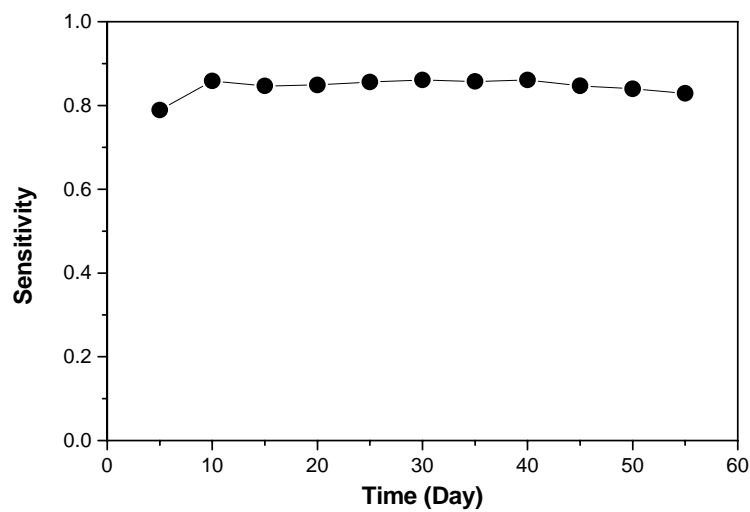


Fig. 10. Stability of 1.5 wt. % Pd: NiFe₂O₄ based LPG sensor over time.

4. Conclusion

In summary, (1) we synthesized nanocrystalline NiFe₂O₄ by a using sol-gel citrate method. (2) XRD pattern of NiFe₂O₄ shows nanocrystalline with average particles size 40 nm. (3) The result observed from TEM image was in agreement with XRD results. (4) The material was found to be good sensitive towards LPG in comparison to other reducing gases. (5) Pd incorporation lowered the operating temperature by 100°C and improves the sensing characteristics of LPG.

Acknowledgement

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References

- [1]. K. Tanaka, M. Makita, Y. Shmizugawa, K. Hirao, N. Soga, Structure and high magnetization of rapidly quenched zinc ferrite, *J. Phys. Chem. Solids*, Vol. 59, Issue 9, 1998, pp. 1611-1618.
- [2]. K. Arshak, I. Gaidan, NiO/Fe₂O₃ polymer thick films as room temperature gas sensors, *Thin Solid Films*, Vol. 495, Issue 1-2, 2006, pp. 286-291.
- [3]. L. D. Tung, V. Kolesnichenko, G. Caruntu, D. Caruntu, Y. Remond, V. O. Golub, C. J. O'Connor, L. Spinu, Annealing effects on the magnetic properties of nanocrystalline zinc ferrite, *Physica B*, Vol. 319, Issue 1-4, 2002, pp. 116-121.
- [4]. S. Zhuyikov, T. Ono, N. Yamazoe, N. Miura, High temperature NO_x sensors using zirconia solid electrolyte and zinc-family oxide sensing electrode, *Solid State Ion.*, Vol. 152/153, 2002, pp. 801-807.
- [5]. S. Yuan Chu, T. Min Yan, S. Li Chen, Analysis of ZnO varistors prepared by the sol-gel method, *Ceram. Int.*, Vol. 26, Issue 7, 2000, pp. 733-737.
- [6]. C. Cobianu, C. Savaniu, P. Siciliano, S. Capone, M. Utriainen, L. Niinisto, SnO₂ sol-gel derived thin films for integrated gas sensors, *Sens. and Actuators B*, Vol. 77, Issue 1-2, 2001, pp. 496-502.
- [7]. J. L. Solis, V. Lantto, Gas sensing properties of Sn_xWO_{3+x} mixed oxide thick films, *Sens. and Actuators B*, Vol. 48, Issue 1-3, 1998, pp. 322-327.
- [8]. K. Galatsis, Y. X. Li, W. Wlodarski, K. Kalantar-zadeh, Sol-gel prepared MoO₃-WO₃ thin films for O₂ gas sensing, *Sens. and Actuators B*, Vol. 77, Issue 1-2, 2001, 478-483.
- [9]. L. Lozzi, L. Ottaviano, M. Passacantando, S. Santucci, C. Cantalini, The influence of air and vacuum thermal treatment on the NO₂ gas sensitivity of WO₃ thin films prepared by thermal evaporation, *Thin Solid Films*, Vol. 391, Issue 2, 2001, pp. 224-228.
- [10]. M. Penza, C. Martucci, G. Cassano, NO_x gas sensing characteristics of WO₃ thin films activated by noble metals (Pd, Pt, Au) layers, *Sens. and Actuators B*, Vol. 50, Issue 1, 1998, pp. 52-59.
- [11]. S. V. Manorama, C. V. Gopal Reddy, V. J. Rao, X-ray photoelectron spectroscopic studies of noble metal-incorporated BaSnO₃ based gas sensors, *Appl. Surf. Sci.*, Vol. 174, Issue 2, 2001, pp. 93-105.
- [12]. M. S. Berberich, J. G. Zheng, U. Weimar, W. Gopel, N. Barsan, E. Pentia, A. Tomeacu, The effect of Pt and Pd surface doping on the response of nanocrystalline tin dioxide gas sensors to CO, *Sens. and Actuators B*, Vol. 31, Issue 1-2, 1996, pp. 71-75.
- [13]. L. Chen, S. C. Tsang, Ag doped WO₃-based powder sensor for the detection of NO gas in air, *Sens. and Actuators B*, Vol. 89, Issue 1-2, 2003, pp. 68-75.
- [14]. J. F. Chang, H. H. Kuo, I. C. Leu, M. H. Hon, The effects of thickness and operation temperature on ZnO:Al thin film CO gas sensor, *Sens. and Actuators B*, Vol. 84, Issue 2- 3, 2002, pp. 258-264.
- [15]. N. Izu, W. Shin, I. Matsubara, N. Murayama, The effects of the particle size and crystallite size on the response time for resistive oxygen gas sensor using cerium oxide thick film, *Sens. and Actuators B*, Vol. 94, Issue 2, 2003, pp. 222-227.
- [16]. J. Xu, Q. Pan, Y. a. Shun, Z. Tian, Grain size control and gas sensing properties of ZnO gas sensor, *Sens. and Actuators B*, Vol. 66, Issue 1-3, 2000, pp. 277-279.
- [17]. L. Satyanarayana, K. Madhusudan Reddy, S. V. Manorama, Nanosized spinel NiFe₂O₄: A novel material for the detection of liquefied petroleum gas in air, *Mater. Chem. Phys.*, Vol. 82, Issue 1, 2003, pp. 21-26.

- [18]. M. Fernandez-Garcia, A. Martinez Arias, A. Iglesias-Juez, A. B. Hungria, J. A. Anderson, J. C. Conesa, J. Soria, New strategies for the improvement of Automobile catalysts, *Int. J. Mol. Sci.*, Vol. 2, Issue 5, 2001, pp. 251-262.
- [19]. Y. Wang, J. Chen, X. Wu, Preparation and gas sensing properties of perovskite type SrFeO₃ oxide, *Mater. Lett.*, Vol. 49, Issue 6, 2001, pp. 361-364.

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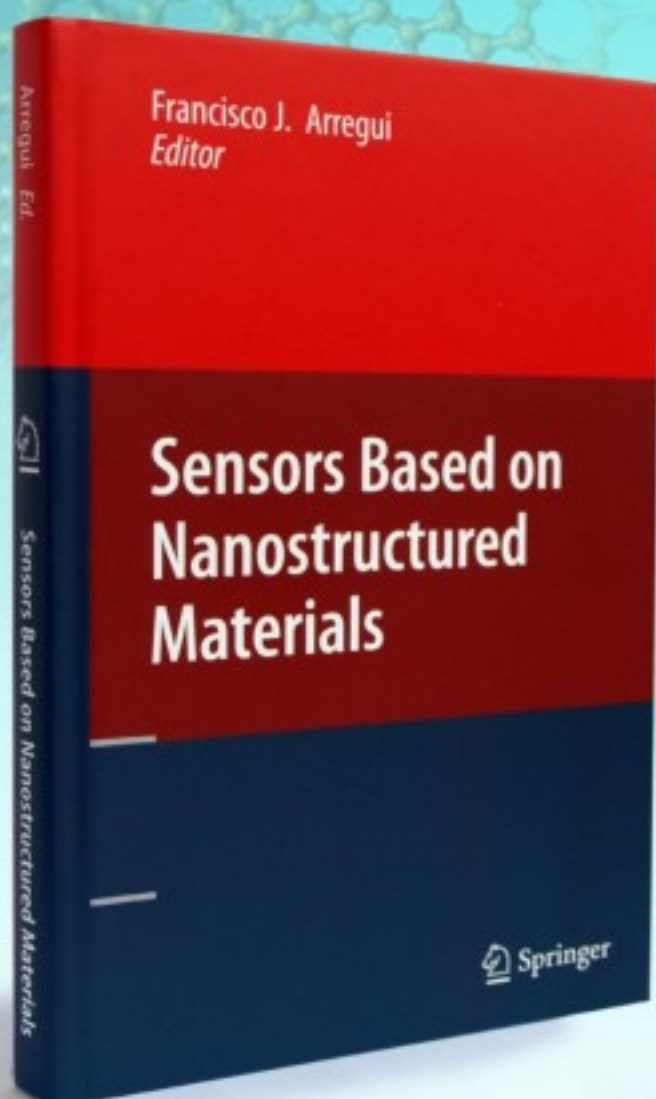
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