Structural and Sensing Characteristics of CdS-TiO_2 film as LPG Sensor at Room Temperature

Abstract

The structural properties and sensing behavior of liquefied petroleum gas (LPG) for cadmium sulphide (CdS) doped titanium dioxide (TiO_2) composite film is investigated. Undoped TiO_2 and 1 wt % CdS doped TiO_2 films are grown onto alumina substrate. Structural properties are investigated using X-Ray diffraction (XRD). The XRD measurement reveals that the crystallites sizes of TiO_2 were found 25.6 nm and 22.6 nm for undoped TiO_2 and CdS-TiO_2 film respectively. The CdS content reduced the crystallite size. The fabricated undoped and CdS doped TiO_2 composite are used as a sensing film for detection of LPG at 25 ^{0}C. The variation in resistance of the fabricated sensor undoped TiO_2 (S_1) and 1 wt% CdS-TiO_2 (S_2) is measured varying the concentration of LPG (0-5000 ppm) in air ambient at room temperature. We observed that S_2 sensor show maximum response to LPG (35%) which is 2.5 times more than S_1 for concentration of LPG 5000 ppm. The response and recovery time of fabricated sensor are 130 sec and 350 sec. Thus, CdS-doped TiO_2 film is promising sensing film for the detection of LPG at 25 ^{0}C.

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Introduction

First resistive type sensor for detection of inflammable gases were reported in 1961 by Seiyama et-al [1]. At the same time Taguchi developed a detector (based on semiconductor oxide) named TGS for LPG leakages as the first sensor commercialized on a large scale [2-3]. Within last 75 years, several researchers were dedicated to chemical sensors focusing on sensing materials, device design and electronics.

Review of Literature

The liquefied petroleum gas (LPG) is one of extensively used but potentially hazardous gas and its detection is particularly important, because explosion accident may be caused when it leaks out accidentally or by mistake. So the detection of LPG in domestic tool must be no false or missing alarms during cooking, which requires the equipment to identify LPG [4-6]. Among the gas sensors TiO_2 based gas sensors have been widely used because of their inert surface properties and high sensing abilities [7]. In recent years, the extraordinary sensitivity of TiO_2 towards H_2 [8], CO [9], methane [10], ethanol [11] etc has been reported.

Yadava et-al reported a solid-state titania-based gas sensor for liquefied petroleum gas detection at room temperature. They estimated that crystallite size range 30-75 nm and average sensitivity of sensor was 1.7 [12]. Mohmmed et-al reports that, In situ aqueous synthesis of silver nanoparticles supported on titanium as active electro-catalyst for the hydrogen evolution reaction and the results show that the Ti substrate loaded with the highest population of AgNPs exhibits the most effective electro-catalytic activity towards the HER, even better than platinum [13].

Aim of the Study

The present work, we investigated the structural and sensing properties of 1 wt% CdS-doped TiO_2 thick film deposited on glass substrate. We observed that, from XRD the crystallite size reduces with CdS doping. The reduction of size improves the sensitivity of the fabricated materials since reduction in nanometric size with CdS enhance its surface area. The response of the sensor enhanced 60 % with 1 wt% CdS doping.

Fabrication of Film

In the laboratory Initially, TiO_2 powder are grinded in porcelain disc using top to bottom approach for 1 hour, solvent CH_3COOH acid and labolin is added and paste is prepared. This paste is rolled over alumina substrate using glass rod (sensor S_1). Further, 1wt% CdS is added into TiO_2 powder and paste is prepared and deposited on alumina substrate (S_2). The fabricated undoped TiO_2 film and CdS doped CdS-TiO_2 composite films are fried at 300 ^{0}C for 45 min. Flow chart fabrication of film is presented in figure 1.

Table 1. Crystallite Size and Lattice Strain Investigate from XRD Measurement.

Wt % Cds	Crystallite Size (nm)	Lattice Strain (nm)	Response %
0	25.66	0.0064	14
1	22.58	0.0073	35

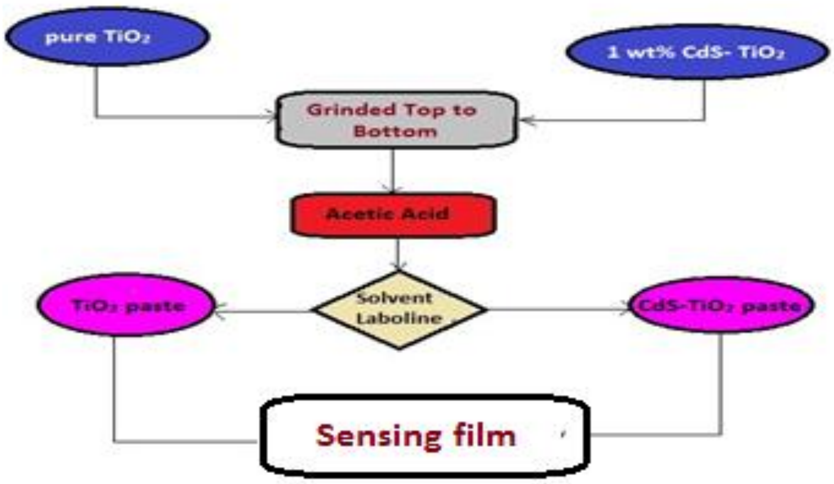

Figure 1. Flow Chart of Fabrication of Film

Results and Discussion

3.1 XRD

The structural properties of fabricated sample were analyzed using XRD with Cu-Kα radiation as source having wavelength 1.546 Å. The crystallite size was estimated using Debye Scherer formula [14-15].

$$d = \frac{k\lambda}{\beta.\cos\theta} \qquad (1)$$

Where β is full width half maxima of peak, λ is X-ray wavelength, θ is the Braggs angle and k is shape factor (~ 0.94). Fig.2 shows the XRD pattern of S_1 and S_2. The high intensity peak, centre at 2θ ~ 25.3^0 is assigned to (101) with full with half maxima (FWHM) ~ 0.3314 and FWHM ~ 0.3769 for S_1 and S_2 respectively. The crystallite size found to be 25.66 nm (with lattice strain 0.0064) and 22.058 nm (lattice strain 0.0073) for S_1 and S_2 respectively. In the XRD analysis at peak (101) shows the fabricated films are anatase crystalline phase. The reduction of crystallinity with CdS doping were improve the sensing properties.

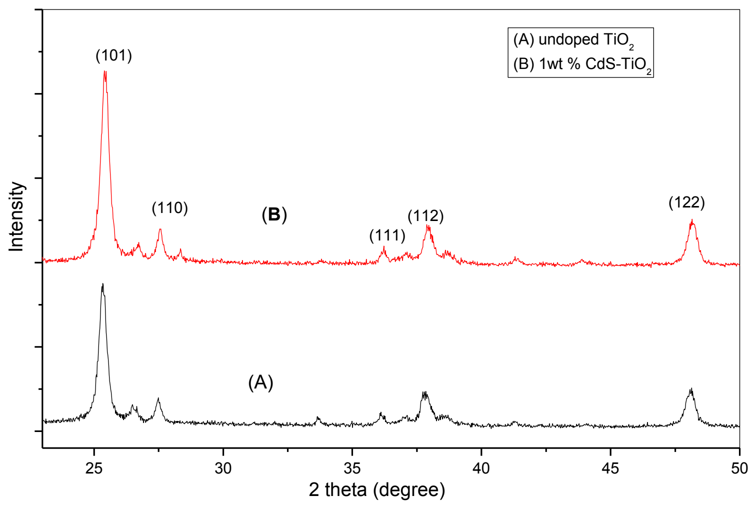

Figure 2. XRD pattern of (a) S_1 film (b) S_2 film

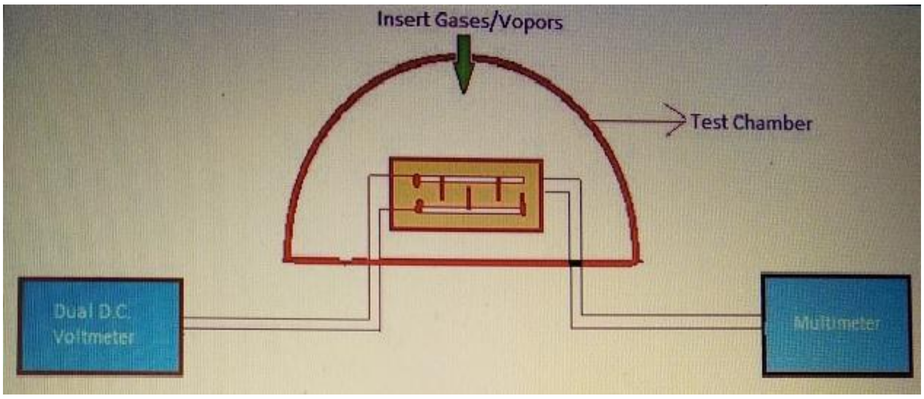

Figure 3. Experimental Setup for Sensing of LPG

3.2 Sensing Measurement and Mechanism

The prepared CdS-doped TiO_2 films were examined for sensing behavior for various concentration of LPG in ppm level (0-5000) at 25^0C. The experimental setup is shown in figure 3.

Percentage change of sensor response for the sensing materials is defined as

$$SR = \frac{|Ra - Rg|}{Ra} \text{x}100 \qquad (2)$$

Where R_a is resistance in air and R_g is resistance in presence of LPG[16,17] It is observed from figure 4 that response of S_1 and S_2 are found 14% and 35% respectively and the response of S_2 is 2.5 time than S_1 (Table1). The LPG sensing mechanism is explained on the basis of change in resistance of oxide thick film. Initially oxygen adsorbed on the surface of film and extracts the e^- from its conduction band to form of O^{-2} species shown in following reaction.

$$O_{2\ (gas)} \rightarrow O_{2\ (ads)}$$

$$O_2\ (ads) + e^- \rightarrow O^{-2}$$

When we exposed LPG on the surface of film, LPG react with chemisorbs oxygen, chemisorptions is stronger interaction that, show a better sensitivity. Overall reaction is fallow as

$$2C_nH_{2n-2} + 4O^{-2} \rightarrow 2C_nH_{2n}O + 2H_2O + 8e^-$$

Response and recovery time is most important factor for sensing parameter; response time to determine when 90% of its maximum value of response and time taken by sensor response goes to its initial state is known as recovery time. From Figure 5 observed that, response time of S_2 130 sec with recovery time 350 sec

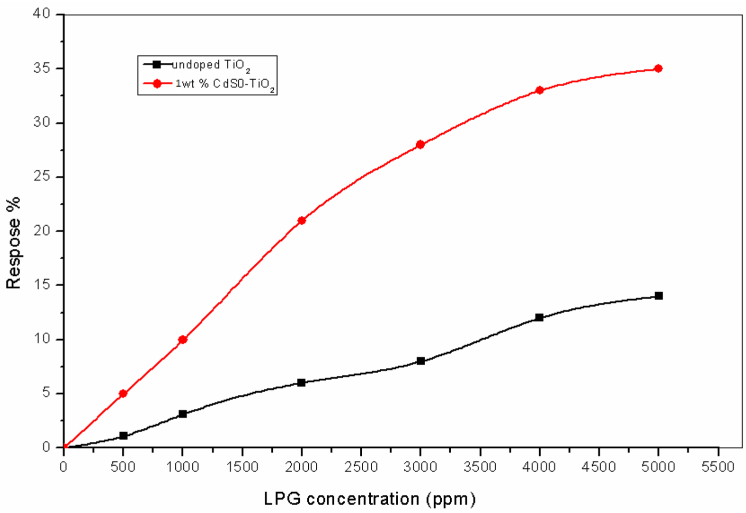

Figure 4.Response of LPG for undoped, 1wt% CdS doped TiO_2

Conclusion

In the present work the structural and sensing properties of CdS-TiO_2 composite film were studied. Structural analysis reveals that crystallite sizes are found in nano metric range and reduces with CdS contents. The reduction of crystallinity and adsorbed oxygen influence the sensing behavior of the CdS-TiO_2 composite films. The response of S_1 and S_2 were studied with exposure of LPG in (0-5000 ppm) at room temperature. It is found that CdS-TiO_2 (S_2) shows maximum response (35%) for tested LPG gas. The response time of the sensor S_2 is 130 second. We conclude that 1 wt% CdS doped TiO_2 composite films is a suitable composite films and can be used for the sensing of LPG gases room temperature.

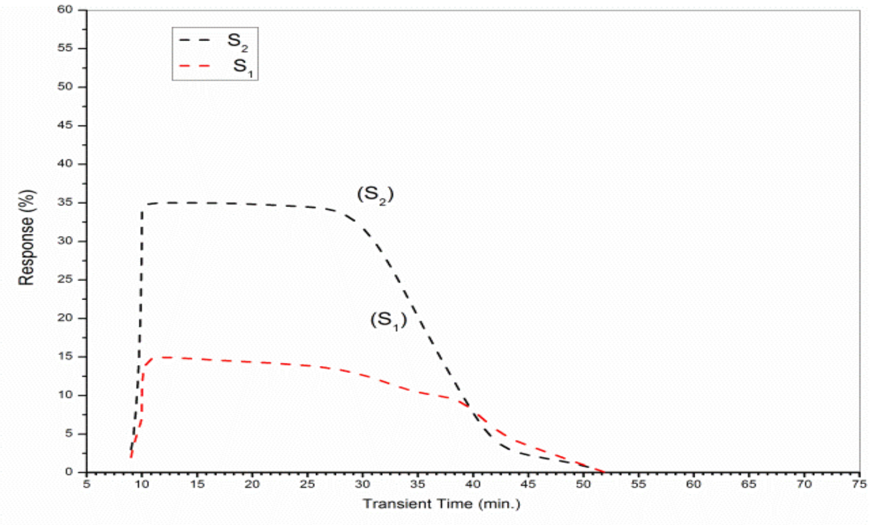

Figure 5.Transient time vs. response for S_2 Sensor

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References

Chiba A, Yaauchi S (editor) (1992), Chem. sens. Tech. 4 elesevier

Mardarea D, Iftimiea N, Lucaa D (2008), TiO_2 thin films as sensing gas materials , Journal of Non Crystalline Solids 354: 4396–4400.

Mohammed A, Amin, Sahar A, Fadlallah, Ghaida S, Alosaimi (2014), In situ aqueous synthesis of silver nanoparticles supported on titanium as active electrocatalyst for the hydrogen evolution reaction, international journal o f hydrogen energy 39: 19519-19540.

Miyazaki H, Hyodo T, Shimizu Y, Egashira M (2005) Hydrogen sensing properties of anodically oxidized TiO2 film sensors: effects of preparation and pretreatment conditions. Sensors and Actuators B: Chemical; 108: 467–72.

Nakahara T and Koda H (1991), Chemical sensor technology, 3, elesevier

Seiyama T, Kato A, Fujiishi K and Nagatani M (1962) Anal. Chem., 34: 1502

Shukla T. (2012), Synthesis of Tin Oxide Thick Film and Its Investigation as a LPG Sensor at Room Temperature, Journal of Sensor Technology, 2: 102-108

Tang H, Prasad K, Sanjinés R, Lévy F. (1995) TiO_2 anatase thin films as gas sensor, Sensors and Actuators B: Chemical 26 :71–75.

Vishwakarma A K, Yadav L (2018), Microstructural properties and sensing behavior of SnO_2 gas sensor, International Research Journal of Management Science & Technology, 9: 239-244

Vishwakarma A K, Yadava L (2018), Fabrication and characterization of nano-TiO_2 thin film using physical vapor deposition method, Adv. Sci. Eng. Med. 10: 728-732.

Vishwakerma A.K.Yadava L (2018) Detection of propanol gas using titaniam dioxide based thick tilm, IOP Conf.series; Materials sciencesand Engineering 404:o12020.

Vishwakarma A K, Yadava L (2018), Fabrication and characterization of CdS doped ZnO nano thick films, Vacuum, 155: 214–218.

Yadava B C, Yadav A, Shukla T, and Singh S (2009)., Experimental Investigations on Solid State Conductivity of Cobalt-zincate Nanocomposite for Liquefied Petroleum Gas Sensing, Sensor Letters, 7 : 1119- 1123

Yadava L, Verma R, and Dwivedi R (2010), Sensing properties of CdS doped SnO_2 thick film sensor, Sensors and Actsuators B: Chemical 144: 37.

Yadav B C, Yadav A, Shukla T and Singh S (2011), Solid-state titania-based gas sensor for liquefied petroleum gas detection at room temperature, Bull. Mater. Sci., 34: 1639–1644.

Youn-Ki Juna, Hyun-Su Kima, Jong-Heun Leeb, Seong-Hyeon Hong (2006), CO sensing performance in micro-arc oxidized TiO_2 films for air quality control, Sensors and Actuators B: Chemical, 120: 69–73.

Zuruzi et al (2007), Metal Oxide Nano-sponges as Chemical Sensors: Highly Sensitive Detection of Hydrogen with Nanoporous Titania, Angew. Chem. Int. Ed. 46: 4298 – 4301