

Asian Resonance

Structural and Sensing Characteristics of CdS-TiO₂ film as LPG Sensor at Room Temperature



Ankit Kumar Vishwakarma

Thin Film Laboratory,
Department of Physics,
Deen Dayal Upadhyaya
Gorakhpur University,
Gorakhpur, U.P.



Lallan Yadava

Thin Film Laboratory,
Department of Physics,
Deen Dayal Upadhyaya
Gorakhpur University,
Gorakhpur, U.P.

Abstract

The structural properties and sensing behavior of liquefied petroleum gas (LPG) for cadmium sulphide (CdS) doped titanium dioxide (TiO₂) composite film is investigated. Undoped TiO₂ and 1 wt % CdS doped TiO₂ films are grown onto alumina substrate. Structural properties are investigated using X-Ray diffraction (XRD). The XRD measurement reveals that the crystallites sizes of TiO₂ were found 25.6 nm and 22.6 nm for undoped TiO₂ and CdS-TiO₂ film respectively. The CdS content reduced the crystallite size. The fabricated undoped and CdS doped TiO₂ composite are used as a sensing film for detection of LPG at 25 °C. The variation in resistance of the fabricated sensor undoped TiO₂ (S₁) and 1 wt% CdS-TiO₂ (S₂) is measured varying the concentration of LPG (0-5000 ppm) in air ambient at room temperature. We observed that S₂ sensor show maximum response to LPG (35%) which is 2.5 times more than S₁ for concentration of LPG 5000 ppm. The response and recovery time of fabricated sensor are 130 sec and 350 sec. Thus, CdS-doped TiO₂ film is promising sensing film for the detection of LPG at 25 °C.

Keywords: CdS -TiO₂, LPG sensor; XRD.

Introduction

First resistive type sensor for detection of inflammable gases were reported in 1961 by Seiyama et-al¹. 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 scale²⁻³. 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 LPG⁴⁻⁶. Among the gas sensors TiO₂ based gas sensors have been widely used because of their inert surface properties and high sensing abilities⁷. In recent years, the extraordinary sensitivity of TiO₂ towards H₂⁸, CO⁹, methane^[10], ethanol¹¹ 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 1.7¹². Mohammed 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 platinum¹³.

Aim of the Study

The present work, we investigated the structural and sensing properties of 1 wt% CdS-doped TiO₂ 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, TiO₂ powder are grinded in porcelain disc using top to bottom approach for 1 hour, solvent CH₃COOH acid and labolin is added and paste is prepared. This paste is rolled over alumina

E: ISSN No. 2349-9443

Asian Resonance

substrate using glass rod (sensor S₁). Further, 1wt% CdS is added into TiO₂ powder and paste is prepared and deposited on alumina substrate (S₂). The

fabricated undoped TiO₂ film and CdS doped CdS-TiO₂ composite films are fried at 300 °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

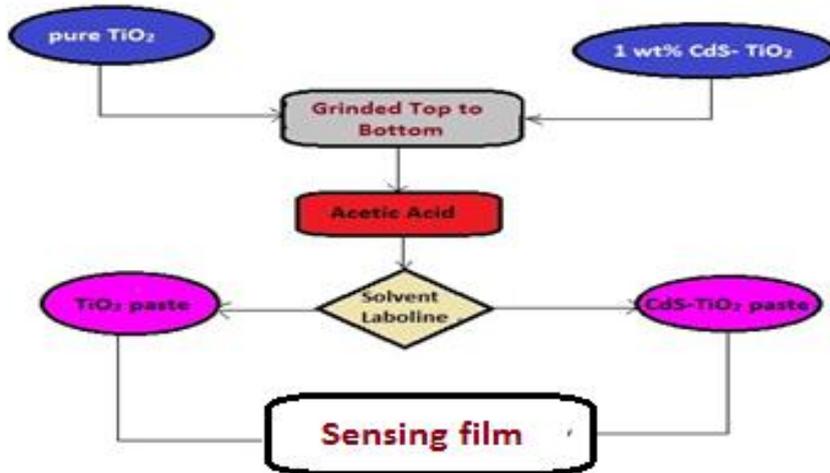


Figure 1. Flow Chart of Fabrication of Film

Results and Discussion

3.1 XRD

The structural properties of fabricated sample were analyzed using XRD with Cu-K α radiation as source having wavelength 1.546 Å. The crystallite size was estimated using Debye Scherer formula¹⁴⁻¹⁵.

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

Where β is full width half maxima of peak, λ is X-ray wavelength, θ is the Bragg's angle and k is shape factor (~ 0.94). Fig.2 shows the XRD pattern of

S₁ and S₂. The high intensity peak, centre at $2\theta \sim 25.3^\circ$ is assigned to (101) with full width half maxima (FWHM) ~ 0.3314 and ~ 0.3769 for S₁ and S₂ respectively. The crystallite size found to be 25.66 nm (with lattice strain 0.0064) and 22.058 nm (lattice strain 0.0073) for S₁ and S₂ 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.

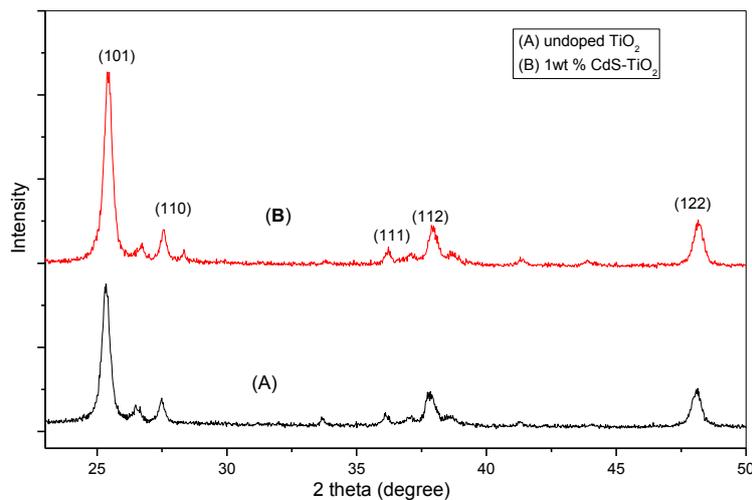


Figure 2. XRD pattern of (a) S₁ film (b) S₂ film

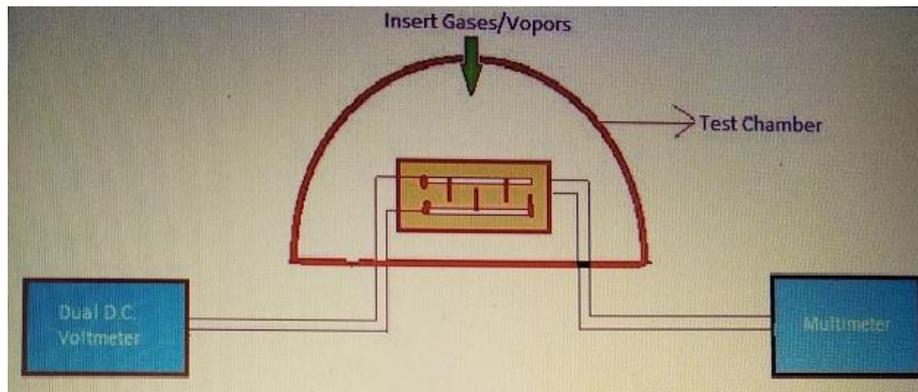


Figure 3. Experimental Setup for Sensing of LPG

3.2 Sensing Measurement and Mechanism

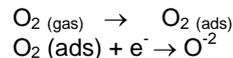
The prepared CdS-doped TiO₂ films were examined for sensing behavior for various concentration of LPG in ppm level (0-5000) at 25°C. The experimental setup is shown in figure 3.

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

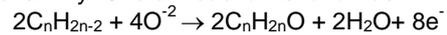
$$SR = \frac{|R_a - R_g|}{R_a} \times 100 \quad (2)$$

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 S₁ and S₂ are found 14% and 35% respectively and the response of S₂ is 2.5 times than S₁ (Table 1). 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.



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



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 S₂ 130 sec with recovery time 350 sec

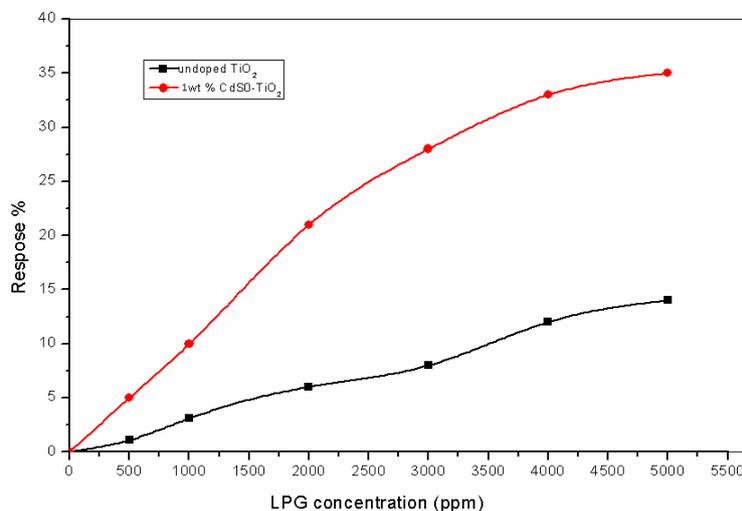


Figure 4. Response of LPG for undoped, 1wt% CdS doped TiO₂

Conclusion

In the present work the structural and sensing properties of CdS-TiO₂ 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-TiO₂ composite films. The response of S₁

and S₂ were studied with exposure of LPG in (0-5000 ppm) at room temperature. It is found that CdS-TiO₂ (S₂) shows maximum response (35%) for tested LPG gas. The response time of the sensor S₂ is 130 second. We conclude that 1 wt% CdS doped TiO₂ composite films is a suitable composite films and can be used for the sensing of LPG gases room temperature.

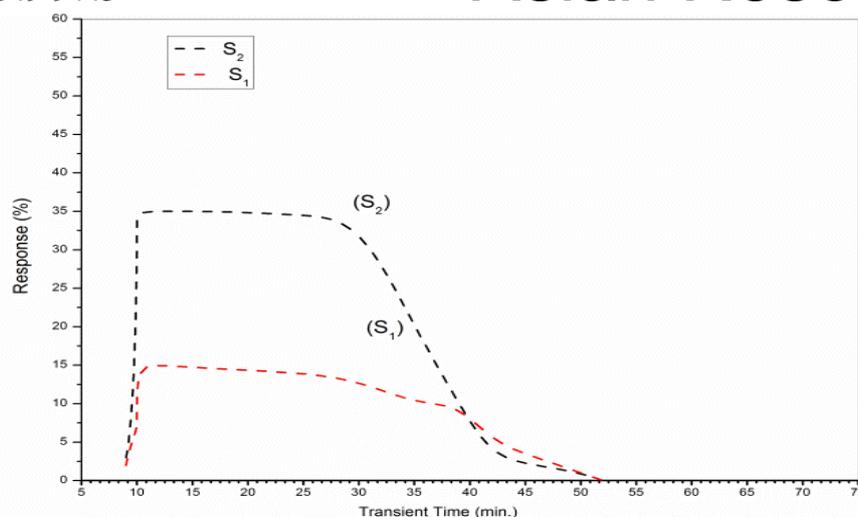


Figure 5. Transient time vs. response for S₂ Sensor

Acknowledgment

Authors thankfully acknowledge to Institute of UGC-DAE, CSR Indore for characterization of film using XRD.

References

- Seiyama T, Kato A, Fujiiishi K and Nagatani M (1962) *Anal. Chem.*, 34: 1502
- Nakahara T and Koda H (1991), *Chemical sensor technology*, 3, Elsevier
- Chiba A, Yaauchi S (editor) (1992), *Chem. sens. Tech.* 4 Elsevier
- 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
- 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
- Vishwakarma A K, Yadav L (2018), *Microstructural properties and sensing behavior of SnO₂ gas sensor*, *International Research Journal of Management Science & Technology*, 9: 239-244
- 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.
- 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
- Youn-Ki Juna, Hyun-Su Kima, Jong-Heun Leeb, Seong-Hyeon Hong (2006), *CO sensing performance in micro-arc oxidized TiO₂ films for air quality control*, *Sensors and Actuators B: Chemical*, 120: 69–73.
- Mardarea D, Iftimiea N, Luca D (2008), *TiO₂ thin films as sensing gas materials*, *Journal of Non Crystalline Solids* 354: 4396–4400.
- Tang H, Prasad K, Sanjinés R, Lévy F. (1995) *TiO₂ anatase thin films as gas sensor*, *Sensors and Actuators B: Chemical* 26 :71–75.
- 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.
- 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 of hydrogen energy* 39: 19519-19540.
- Vishwakarma A K, Yadava L (2018), *Fabrication and characterization of nano-TiO₂ thin film using physical vapor deposition method*, *Adv. Sci. Eng. Med.* 10: 728-732.
- Vishwakarma A K, Yadava L (2018), *Fabrication and characterization of CdS doped ZnO nano thick films*, *Vacuum*, 155: 214–218.
- Yadava L, Verma R, and Dwivedi R (2010), *Sensing properties of CdS doped SnO₂ thick film sensor*, *Sensors and Actuators B: Chemical* 144: 37.
- Vishwakarma A.K, Yadava L (2018) *Detection of propanol gas using titanium dioxide based thick film*, *IOP Conf. series; Materials sciences and Engineering* 404: 012020.