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Influence of Liquid Petroleum Gas on the Electrical Parameters of the WO_3 Thick Film

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Abstract: In this work, the WO_3 thick films were prepared by standard screen-printing technology. These films were characterized by x-ray diffraction (XRD) measurements and scanning electron microscopy (SEM). Influence of LPG on the electrical properties of the prepared WO_3 thick film is reported. It was observed that the slope of the Arrhenius curves of the WO_3 thick film decreased as the medium changed from pure air to 100 ppm LPG in air. From I-V characteristics, it was observed that the WO_3 thick film exhibit highest sensitivity to 50 ppm LPG in air at 400^oC.

Key words: WO_3 thick film, screen printing, arrhenius curves, I-V characteristic, LPG

1. Introduction

Gas sensors are playing an increasingly important role in environmental monitoring, control of chemical processes, remote sensing, in space, agricultural and medical applications. Semiconductors oxide based gas sensors prepared by the screen printing method have certain advantages with respect to other type of gas sensors. To detect small concentration of a reactive gas in air, the surface reactions are much more relevant than bulk changes, so the specific surface of gas sensitive elements must be as high as possible. The screen printing technology is adequate for satisfying such a primary requirement. In addition to high sensitivity, thick film sensors have high stability and simple construction at low cost [1, 2].

Gas sensors based on ZnO, SnO_2, Fe_2O_3 and WO_3 etc. in the thick film form have been developed for detection and control of gases such as CO, CO_2, H_2, H_2S, NH_3, NO_2, LPG, methane, butane and ethanol vapor [2-12].

WO_3 is an n-type wide band gap semiconductor. Its electrical conductivity results from point defects which are native, mainly oxygen vacancies that act as donors. This unique electrical property of WO_3 makes it useful for detection of variety of toxic and flammable gases [3, 4, 13-15]. A.R. Phani et. al reported LPG sensor based on SnO_2 [16]. Also C. V. Gopal Reddy et. al reported LPG sensor based on barium stannate ($BaSnO_3$) [17]. D.S. Lee et. al reported gas sensing studies for WO_3 film for oxidizing gas NO_2, in terms of arrhenius curves [18]. Also gas sensing studies in terms of I-V curves of WO_3 doped SnO_2 films in gas medium was reported by D.H.Yun et. al [19].

In this paper, we have reported the influence of LPG on the electrical parameters of the prepared WO_3 thick films in terms of Arrhenius curves and I-V characteristics. The WO_3 thick films were prepared by using the screen printing technique.

2. Experimental

The WO_3 powder (purity ~ 99.99%) was mechanically milled in an acetone medium using Fisher type electric agate pestle and mortar for 24 hours. After drying at 200^0C for 20 min, the powder (99.5 %) was thoroughly mixed with some organic and inorganic compounds to achieve proper thixotropic properties of the paste. The paste, thus formed was screen printed onto an alumina substrate. The films were allowed to stabilize at room temperature for 24 hours and then the films were cured at 800 ^{0}C for 1h. Our group has reported the details of the preparation method of the WO_3 thick films and it was found that strongly adherent WO_3 thick films can be obtained on the alumina substrate [20].

The structural properties of the WO_3 thick films were investigated using X-ray diffraction (XRD) technique. The X-ray diffraction patterns were recorded with a Rigaku diffractometer (Miniflex Model, Rigaku, Japan) having Cu K_α (λ = 0.1542 nm). Scanning electron microscopy (SEM) was employed to characterize the surface morphology with a Leica Cambridge 440 Microscope (U.K.).

The measurements of electrical characteristics such as Arrhenius curves, I-V characteristics were carried out in a static gas chamber. The substrate was kept directly on a heater in the closed gas chamber. With the help of air tight syringe, specific concentration of the gas was introduced in the chamber pre-filled with air at atmospheric pressure. Temperature measurement was made by standard Al-Cr thermocouple. Electrical point contacts to the film were made with the help of copper wire and silver paste. Resistance measurement was done by simple two probe method by using a sensitive digital multi meter (METRAVI 603). Voltage and Current measurement were done by using Digital Dc Micro Voltmeter ammeter (Testronix 8).

3. Results and Discussions

The X-ray diffraction pattern of the WO_3 thick film is shown in Fig.1. The main diffraction peaks at 2θ values of 23.6^o, 24.2 ^{o}, 33.8 ^{o},42.2^o, 50.8 ^{o}, 55.2^0 and 56.4^o clearly reveal the formation of triclinic phase of WO_3 (JCPDS Data card 83-0948).

The surface morphology of the WO_3 thick film deposited on the alumina substrate is as shown in Fig.2. It clearly shows that the surface of WO_3 films is porous and forms channels with the bundles of grains.

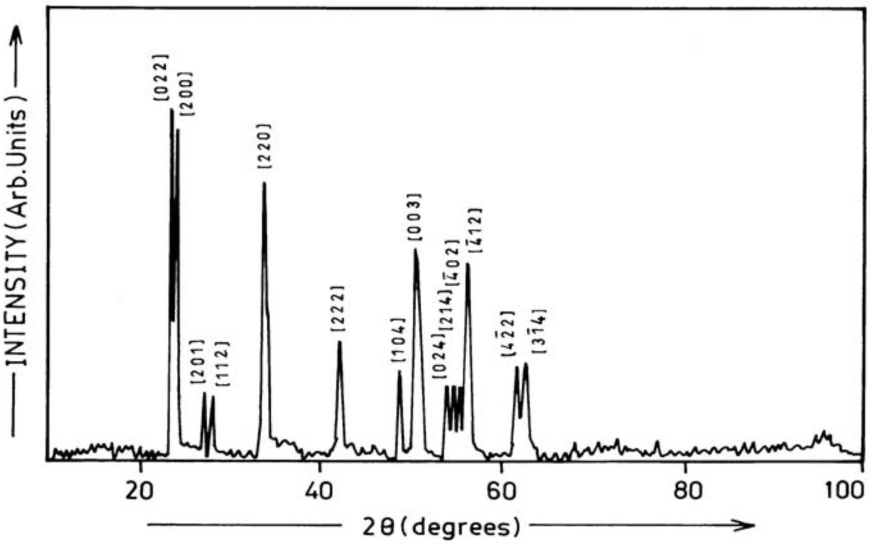

Fig. 1. The X-ray diffraction pattern of the WO_3 thick film.

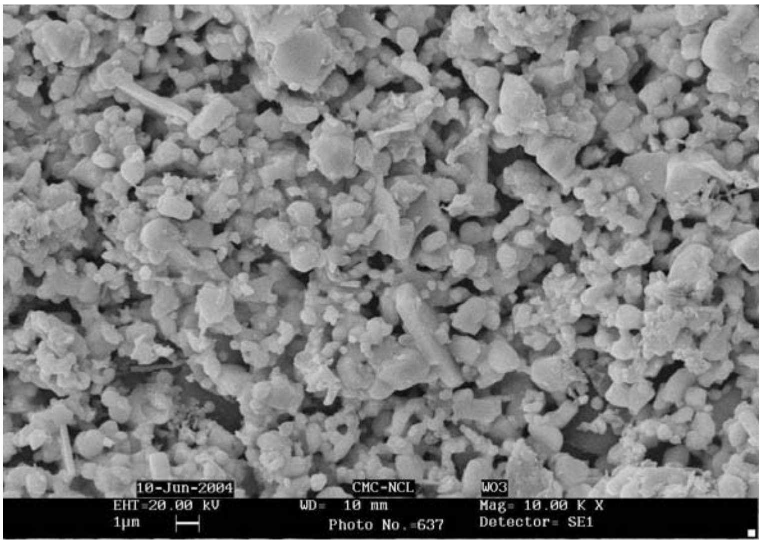

Fig. 2. SEM image of the screen printed WO_3 thick film on the alumina substrate.

The influence of LPG on the electrical parameters of the prepared WO_3 thick film was investigated in terms of Arrhenius curves and I-V characteristics.

The Arrhenius curves (Fig.3.) for the WO_3 thick film were recorded in pure air and adding known concentration of LPG to pure air. It was observed that the slope of the Arrhenius curves decreased as the medium changed from pure air to 100 ppm LPG in air. The activation energies calculated from these curves are 0.60eV, 0.37eV and 0.33eV for pure air, 50 ppm LPG in air and 100ppm LPG in air respectively. This decrease in the activation energy can be attributed to decrease in the height of the energy barrier for charge transport with increase in the concentration of the reducing LPG. Lee et al have reported increase in the activation energy of the WO_3 thick film sensor with increasing NO_2 (oxidizing gas) concentration. They have attributed this result to increase in the height of the energy barrier with increase in the oxidizing NO_2 gas concentration [18]. It is observed that the decrease in the activation energy is more for change in medium from pure air to 50ppm LPG in air, than that for 50ppm LPG in air to 100 ppm LPG in air. It is thought that it is caused by saturation of the gas adsorption in surface states at higher gas concentration.

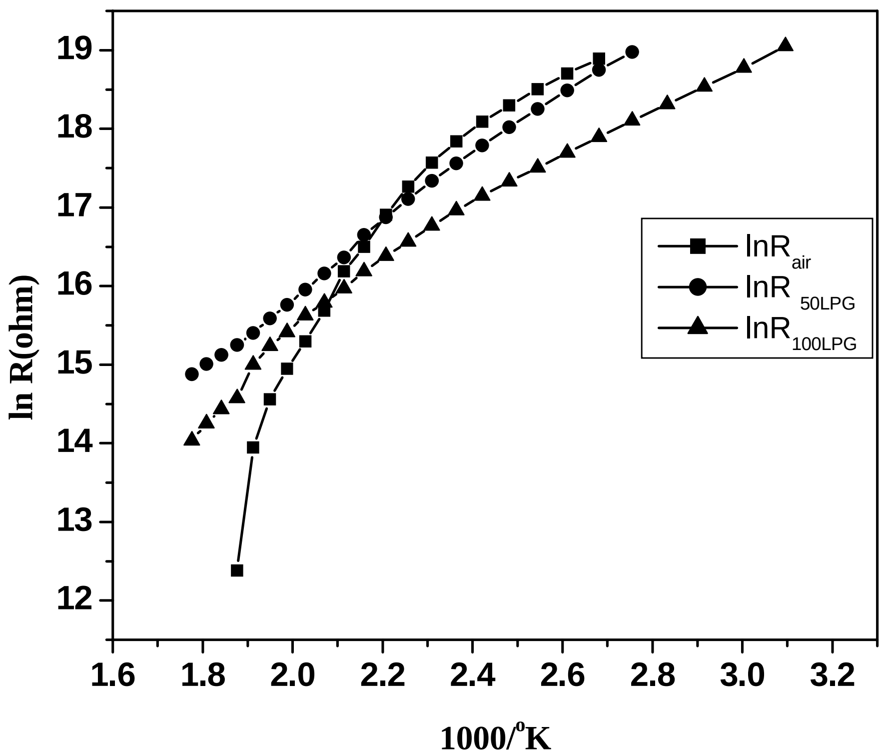

Fig. 3. The Arrhenius curves for WO_3 thick film recorded in pure air, in 50 ppm LPG and in 100 ppm LPG.

The measurement of I-V characteristics (Fig. 4.) of the WO_3 thick film was carried out in pure air and in 50ppm LPG added air medium at different temperatures i.e. 300°C, 350°C and 400°C.

For pure air medium, I-V characteristics are found to be linear and slight increase in the current values was observed for increase in temperature. For LPG added air medium, overall increase in the current values was observed as compared to those for pure air. The increase in the current values was highest at 400°C. At 300°C and 350°C, I-V characteristics were almost linear. At 400°C, slight non-linearity was observed in the I-V characteristics at higher voltages. The highest current values were observed at 400°C. This significant decrease in the resistance of the film in the LPG added air medium at 400°C indicates that the WO_3 thick film exhibit highest sensitivity to 50 ppm LPG in air at 400°C. The mechanism behind the decrease in the resistance of the WO_3 thick films in the LPG added air medium has already been discussed elsewhere [20].

At 400°C, the slight non-linearity at higher voltages may be due to availability of the thermally activated electrons for conduction in addition to the tunneling electrons [21].

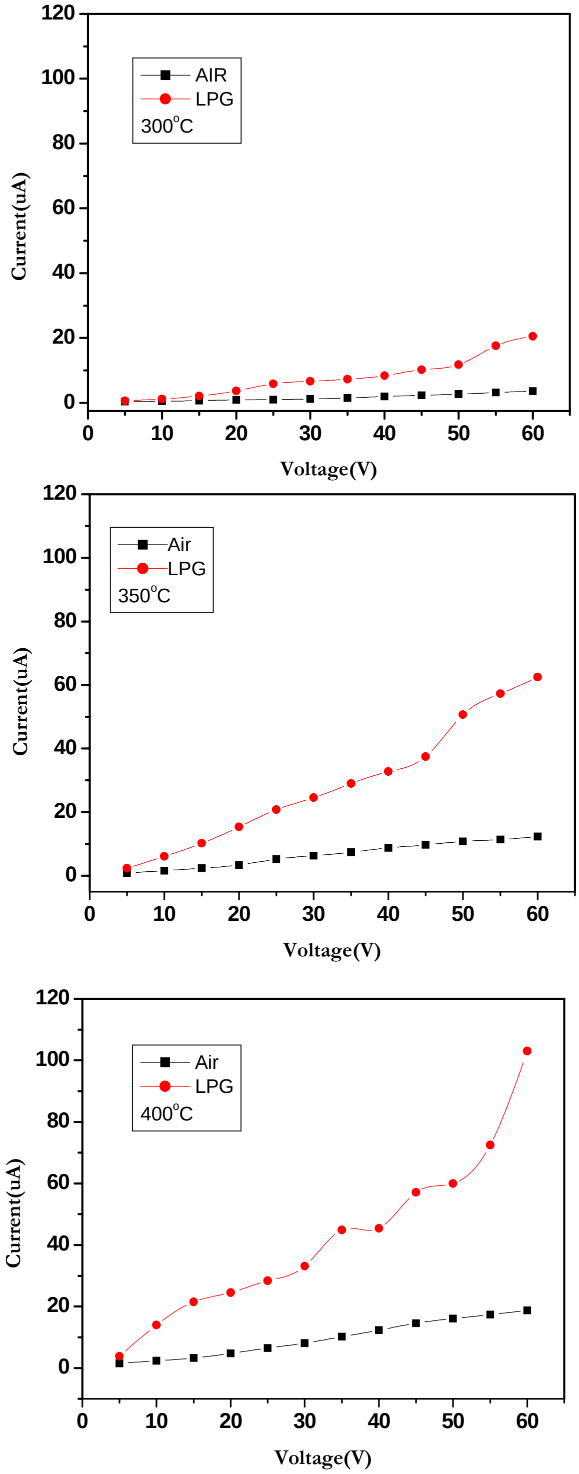

Fig. 4. I/V Characteristics of WO_3 thick film a) 300°C; b) 350°C; c) 400°C.

4. Conclusions

In summary, following conclusions have been drawn from the present investigations –

- The LPG sensing properties of screen printed WO_3 thick films were investigated in terms of Arrhenius curves and I-V characteristics.
- The highest sensitivity was obtained at operating temperature 400^oC.
- All the results have been found to be repeated for three times indicating the reliability of the sensor.
- This study demonstrates the possibility of utilizing WO_3 thick film as a sensor element for the detection of LPG.

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Guide for Contributors

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Sensors & Transducers Journal (ISSN 1726- 5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

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