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Enhanced NO_2 response of surface decorated WO_3 low-cost gas sensors

S.M. Emamjomeh[1,2], L. Lee[3], G.S. Henshaw[3], V. Paolucci, C. Cantalini[1], D.E. Williams[2]
[1] Department of Industrial and Information Engineering and Economics
Via G. Gronchi 18, University of L'Aquila, I-67100 L'Aquila, Italy
[2] School of Chemical Sciences, University of Auckland, 23 Symonds St., Auckland 1010, New Zealand
[3] Aeroqual Ltd., 460 Rosebank Road, Avondale, Auckland 1026, New Zealand

Abstract:

The aim of this work is to enhance the electrical responses of low-cost WO_3 chemo-resistive gas sensors to sub-ppm NO_2 gas concentration through doping with different concentrations of Y_2O_3. Y_2O_3 surface decorated WO_3 gas sensors were prepared by screen-printing and annealed at 800 °C. X-ray Diffractometry (XRD) and Scanning Electron Microscopy (SEM) were used to study the phase evolution and morphology of fabricated films, respectively. Results showed that Y_2O_3 nanoparticles are well dispersed within the bulk WO_3 and have decorated the surface of WO_3 grains. Electrical measurements at 350°C operating temperature, showed that the relative responses (RR) of fabricated sensor to 200 ppb NO_2 is significantly improved by adding just 1% Y_2O_3. Besides, NO_2 adsorption and desorption time (τ_{ads} and τ_{des}) decreased to 75% and 50% of that of undoped sample, respectively.

Key words: WO_3, Y_2O_3, NO_2, Sensitivity, response time.

Nitrogen Oxide NO_x (NO_2 and NO) is toxic to human body and is an air pollutant and a source for acidic rain so that high sensitivity sensors with fast response time are required. Tungsten Oxide is an n-type semiconductor and is a good candidate for NO_2 detection [1] and have been successfully used as low-cost gas sensors for air quality measurement [2]. Doping of pure metal oxides with metals or oxides has shown promising results to overcome their inherent limitations on sensor performance [3].

To fabricate doped low-cost Tungsten Oxide sensors, WO_3 bulk powder was ball milled with different amounts of Y_2O_3 (1, 5 and 10 wt%) in Isopropanol in a planetary ball milling machine for 2 hours at 350 rpm. 10 µm thick film gas sensitive resistors were fabricated by screen-printing of WO_3 and Y_2O_3 surface decorated WO_3 fine grains on a 2x2x0.250 mm alumina sensor substrate with an inter-digitated gold electrode on front side and a platinum heater circuit on the back side and were oven annealed at 800 °C in air. Electrical gas responses of fabricated sensors exposed to 200 ppb NO_2 were measured at temperature range 250-450 °C.

XRD patterns presented in Fig. 1 show the evolution of Y_2O_3 peaks in doped samples. The morphologies of bulk WO_3 and Y_2O_3-WO_3 doped samples are illustrated in Fig. 2. It is shown that the surface of WO_3 grains are well decorated with Y_2O_3 nanoparticles and the decoration percentage improves by increasing the amount of Y_2O_3 with an optimum of 5%. Also, it seems that in sample with 10% Y_2O_3, WO_3 grain growth are a bit restricted. Electrical gas sensing measurements of Y_2O_3 doped WO_3 to 200 ppb NO_2 are presented in Fig.3. As shown in fig.3a, the sensitivity of each film (relative response, R_g/R_a) decreases by increasing the operating temperature, besides, it is obvious that by adding only 1 wt% Y_2O_3 to WO_3 the RR significantly increase, and this improvement continuous by increasing the amount of Y_2O_3 to 5 wt% and stops, so that the RR in Y_2O_3 5% and 10% are almost equal, confirming the doping yield of 5%, also see Table 1. Among different operating temperatures, samples showed faster response and recovery times at 350°C. Fig. 3b represents the normalized electrical responses of doped samples to 200 ppb NO_2 at 350°C. As can be seen, adding 1% Y_2O_3 has greatly enhanced the RR response and decreased adsorption and desorption times (τ_{ads} & τ_{des}) to 75% and 50% of that of undoped WO_3, see table 1. Increasing the amount of dopant gradually increases the RR but depresses the response time.

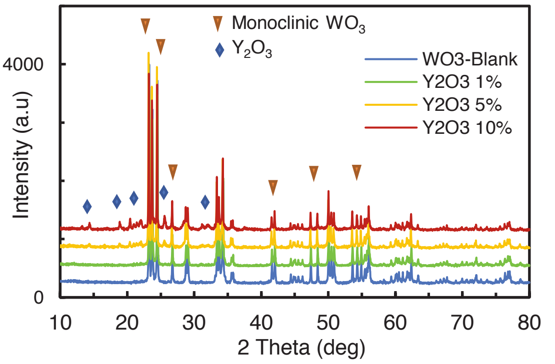

Fig. 1. XRD patterns of WO_3, WO_3-Y_2O_3 1%, WO_3-Y_2O_3 5% and WO_3-Y_2O_3 10%

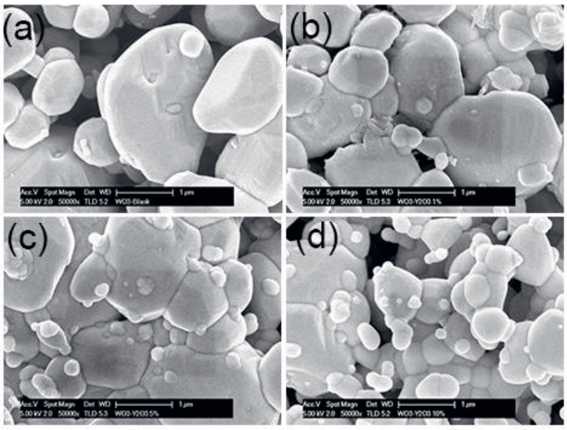

Fig. 2. SEM image of printed films; a) undoped WO_3, b) WO3-1% Y_2O_3, c) WO3-5% Y_2O_3, d) WO3-10% Y_2O_3

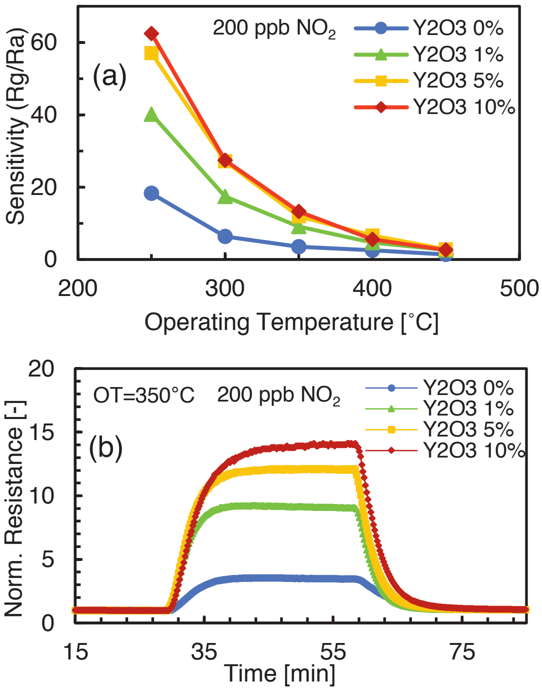

Fig. 3. a) Sensitivity of blank and doped WO_3 screen-printed sensors to 200 ppb NO_2 at temperature range 250-450˚C, b) Electrical response to 200 ppb NO_2 at 350˚C

Table 1- Sensing characteristics of Y_2O_3 doped WO_3 films in terms of Relative Response (RR), and response times (τ_{ads} and τ_{des}) to 200 ppb NO_2 at 350 ˚C.

OT (°C)	Sample	WO_3 (wt%)	Y_2O_3 (wt%)	RR=R_g/R_a [-]	τ_{ads} (min)	τ_{des} (min)
350	Y_2O_3 0%	100	0	3.566	8.01	9.65
	Y_2O_3 1%	99	1	9.091	6.08	4.73
	Y_2O_3 5%	95	5	11.937	7.12	6.25
	Y_2O_3 10%	90	10	13.288	8.33	7.12

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