Optics and Lasers in Engineering 95 (2017) 78–82

Contents lists available at ScienceDirect

Optics and Lasers in Engineering

journal homepage: www.elsevier.com/locate/optlaseng

Sensing characteristics of nanocrystalline bismuth oxide clad-modified fiber optic gas sensor

M. Manjula, B. Karthikeyan, D. Sastikumar*

Department of Physics, National Institute of Technology, Tiruchirappalli 620015, India

ARTICLE INFO

Keywords:
Nanocrystalline Bi_2O_3
Fiber optic gas sensor
Methanol detection
Gas selectivity

ABSTRACT

Gas sensing properties of nanocrystalline bismuth oxide clad – modified fiber optic sensor is reported for ammonia, ethanol, methanol and acetone gasses at room temperature. The output of sensor increases or decreases for certain gasses when the concentration of the gas is increased. The sensor exhibits high response and good selectivity to methanol gas. Time response characteristics of the sensor are also reported.

1. Introduction

Metal oxide-based gas sensors are widely used for detection of toxic gasses due to their higher gas sensitivity [1–4]. These sensors show a good response to oxidizing and reducing gasses through surface reactions [5].

Bismuth oxide (Bi_2O_3) is an important wide band gap semiconductor and studied extensively for gas sensor applications [6]. It has been studied in the form of nanorods [6], nanopowders [7] nanowires [8] and nanobelts [9] for gas sensing applications as nanoparticles can offer large surface area. Different phases (α,β,γ) of Bi_2O_3 nanopowders have been synthesized and their gas sensing properties were studied. It is found that α and β phases are more sensitive to NO gas compared to other common gases [7]. α-Bi_2O_3 nanowires synthesized at a room-temp solution through chemical route exhibited high sensitivity to ppm levels of NO_2 in ambient air [8]. β-Bi_2O_3–core/In_2O_3–shell nanorods showed a good response to NO_2 which is higher than 1.3–1.9 than those of bare β-Bi_2O_3 at 1–5 ppm of NO_2 [6]. Bi_2O_3-core/ZnO shell nanobelts have been fabricated and found to show gas sensing response at ambient temperature, which is 1.2–1.9 times higher than that of pristine Bi_2O_3 nanobelt sensitivity at 1–5 ppm of NO_2 [9]. Bi_2O_3 decorated In_2O_3 nanorod sensor showed good selectivity for ethanol gas over other gasses [10].

Gas sensitivity and selectivity of tin oxide based gas sensor towards CO was improved by doping the base material with Bi_2O_3. It is found that the calcinations of SnO_2: Bi_2O_3 at 800 °C results in the formation of $Bi_2Sn_2O_7$ which enhances sensitivity and selectivity for CO gas (250 °C) [11].

The gas sensing principle, in all the above sensors, is based on a change in the electrical resistance of the sensing medium (Bi_2O_3) when they are exposed to the gas and exhibited large gas sensitivity mostly at higher temperatures. Bi_2O_3 has unique optical properties, such as high refractive index, dielectric permittivity, photoconductivity and photoluminescence [12–14]. However, the optical properties of Bi_2O_3 are not explored for the gas sensing applications.

Metal – oxide clad modified fiber optic gas sensor has been reported for sensing ammonia, methanol, ethanol and acetone gasses [15]. In this technique, Tungsten-halogen lamp was used as light source and a detector with miniature fiber optic spectrometer as sensor response. In this study, red LED is used as light source and a photodiode output voltage as a sensor response. This system provides a simple, portable, low-cost, battery-powered sensing platform.

In this paper, gas sensing properties of bismuth oxide clad modified fiber optic sensor are studied for ammonia, methanol, ethanol & acetone gasses at room temperature. The time response of the sensor is presented.

2. Experimental procedure

2.1. Sensor set-up

Fig. 1c shows the schematic diagram of a fiber optic gas sensor, which consists of multimode plastic (polymethyl methacrylate (PMMA)) step index optical fiber (length 30 cm, diameter 750 µm and numerical aperture 0.5). A red LED (Hamamatsu, L7868 – 02) was used as light source and a silicon photodiode (Hamamatsu, S1133–14), as a detector. The refractive indices of core and cladding of the fiber are 1.492 and 1.402, respectively.

Bismuth oxide nanoparticles were mixed with isopropyl alcohol to form a paste. Gas sensing region was obtained by completely removing

* Corresponding author.
E-mail address: sasti@nitt.edu (D. Sastikumar).

http://dx.doi.org/10.1016/j.optlaseng.2017.04.003
Received 28 September 2016; Received in revised form 10 March 2017; Accepted 15 April 2017
Available online 23 April 2017
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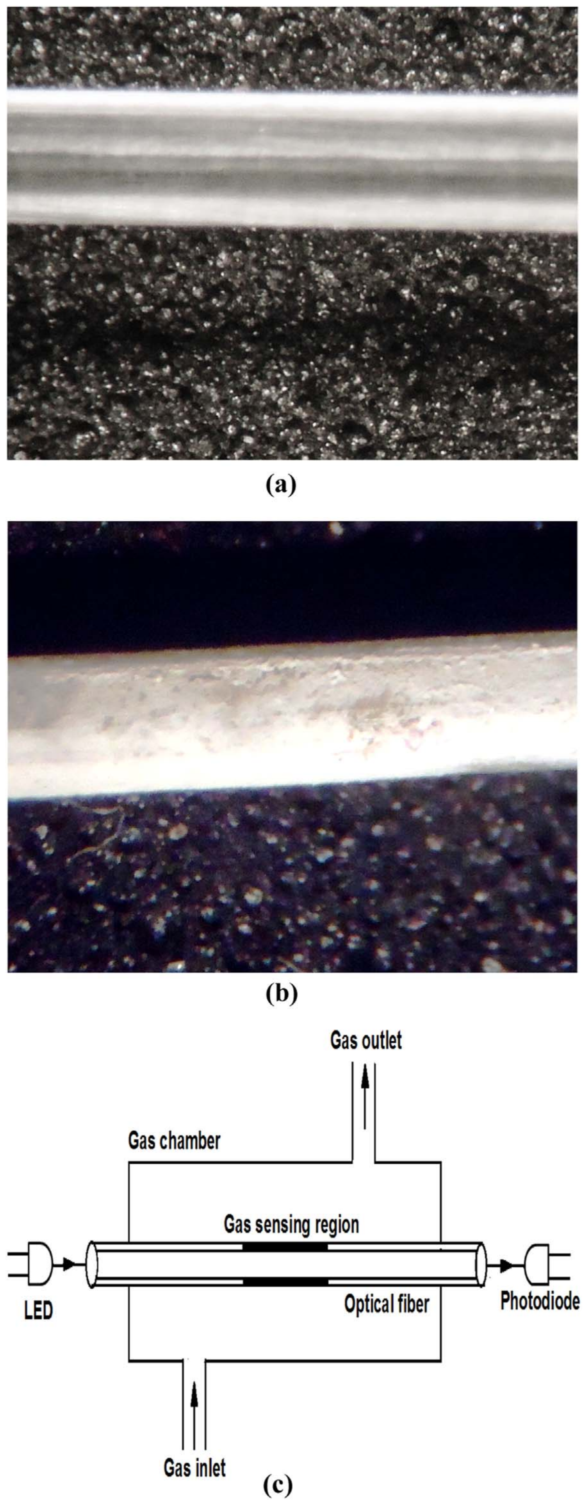

Fig. 1. Surface image of a) clad removed fiber and b) dip coated fiber c) Schematic diagram of a fiber optic gas sensor.

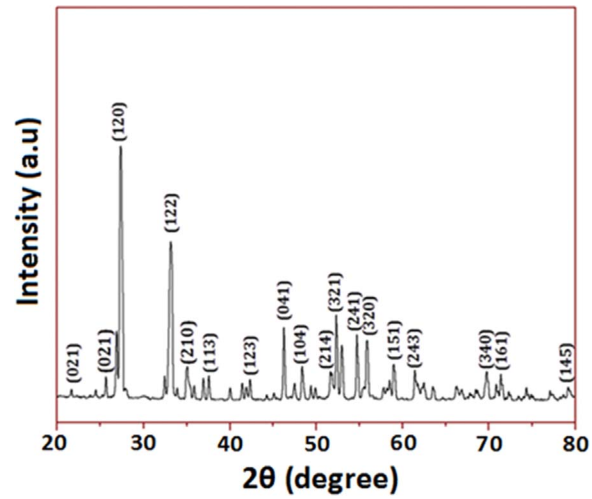

Fig. 2. Powder XRD pattern of Bismuth oxide nanoparticles.

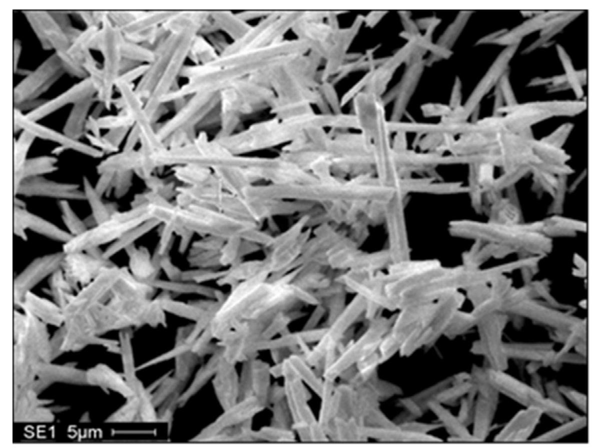

Fig. 3. SEM micrograph of Bi_2O_3.

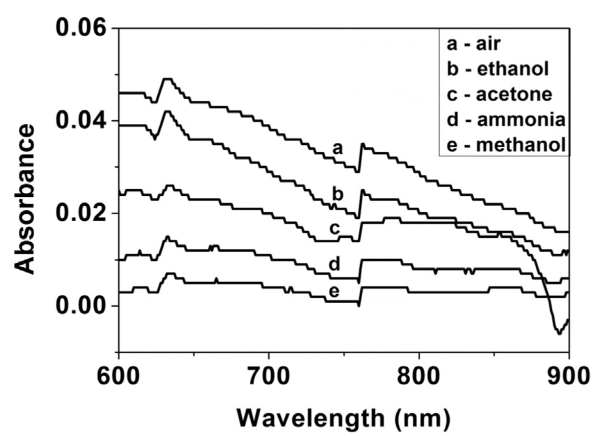

Fig. 4. Absorption spectra of Bi_2O_3 in air, ammonia, ethanol, methanol and acetone.

the cladding of the fiber up to the core about 3 cm in length and replacing it with bismuth oxide paste by dip coating method. The thickness of the coating was about 45 µm which was determined using Micro hardness tester (Shimadzu, HMV-2, Micro hardness tester) by measuring the diameter before (about 700 µm) and after dip coating process (about 745 µm). Fig. 1a and b show surface images of clad removed fiber and dip coated fiber, respectively. Sensing part of the fiber was inserted into a gas chamber after drying at room temperature.

Red LED light was coupled to the sensing fiber. Different concentrations of ammonia, ethanol, methanol & acetone solutions (100–500 ppm) were prepared separately. Vapors produced from the solutions were directly passed into the gas chamber with air (atmospheric air) as carrier gas (2.5 l/min/160 kPa) and the output voltage was recorded using photodiode. The air pressure in the chamber was measured using a manometer. The experiment was performed in a dark

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