DOI 10.5162/EUROSENSORS2025/M3.1.4

Toluene Sensing at Room Temperature using SnO_2 Quantum Dot Decorated rGO Aerogel

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Summary:
This work reports on the fabrication of a reduced graphene oxide (rGO)/tin oxide (SnO_2) aerogel-based sensor for the detection of toluene at room temperature. Unlike conventional high-temperature metal oxide gas sensors, this low-power, cost-effective sensor enables efficient toluene detection under ambient conditions. Our preliminary data clearly show that the rGO/SnO_2 sensor can detect toluene at concentrations as low as 100 parts per billion (ppb); highlighting its potential for the development of practical VOC sensors with enhanced sensitivity.

Keywords: Reduced graphene oxide, tin oxide, aerogel, toluene sensor, chemical sensor

Background, Motivation an Objective

One of the most hazardous volatile organic compounds (VOC) released by automobiles is toluene. It is also extensively used as a solvent in a variety of industries, including paints, glues and cosmetics. Despite its widespread usage in numerous commercial applications, prolonged exposure to toluene can cause major health problems for humans, including damage to the central nervous systems and other important organs [1]. The Health and Safety Executive (HSE) suggests an exposure limit of 100 ppm for a 15 min short-term exposure limit (STEL) and 20 ppm for an 8 hr time-weighted average (TWA) [2]. Therefore, it is crucial to detect toluene at low ppm concentrations for both environmental monitoring and human safety. There have been many articles on the development of highly sensitive toluene sensors based on metal oxide semiconductors (MOS) [3]. Despite showing high sensitivity, their main drawbacks are high operating temperature and power consumption, which limit their practical use in in detecting toluene. Taking this into careful consideration, the current work aims to develop a room-temperature operable sensor for detecting very low concentrations of toluene using SnO_2 quantum dot (QD)-decorated rGO aerogel .

Description of the New Method or System

A surfactant-assisted hydrothermal growth method was employed for the synthesis of rGO/SnO_2 hybrid material. Subsequently, copper chloride and ascorbic acid were added to initiate the gelation and surface doping process, resulting in a highly crosslinked rGO-SnO_2 ink. One layer of the hybrid ink was first spin-coated on a gold interdigitated electrode (IDE) with 10 µm gap substrate at 5000 rpm for 60 s, followed by 60°C annealing for 5 min. Once the substrates had cooled down, a second layer was spin-coated at 2500 rpm for 15 s. The samples were immediately frozen in liquid nitrogen for 10 min and transferred to a freeze dryer (LyoQuest, Telstar) for overnight freeze-drying. The freeze-dried sample was washed with acetone twice and dried in the air (sample denoted as NC2), whereas NC1 refers to the sample that did not undergo the washing step. Both the samples were then annealed at 160°C for 3 h to further reduce the GO before being ready for gas sensing measurements. Fig. 1a shows the image of the uncoated IDE substrates used in the present study. Top-view SEM images (Figs. 1b and 1c) show a uniform, 5nm thick porous aerogel on the sensor substrate. The film bridges a 10 µm gap between two sensor electrode pads. The high porosity of hybrid aerogel with rGO as the skeleton and QDs for sensitisation facilitates efficient gas diffusion and reaction, thus enhancing sensor response and kinetics.

The coated aerogel device was mounted on a PCB and electrical contacts were made using the wire-bonding technique. The fabricated aerogel sensor was placed in a customized sensor chamber connected to the automated gas testing bench, where gas flow rates were controlled by a National Instruments LabVIEW program. The sensor parameters were extracted using NI USB

6343 data acquisition system (DAQ) using an indigenously developed LabVIEW module.

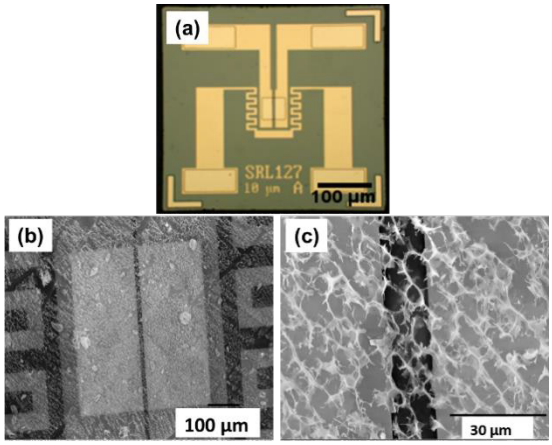

Fig. 1 (a) Photograph of uncoated IDE substrate. SEM images of rGO/SnO_2 aerogel sample with (b) low and (c) high magnifications.

Results

The electrical resistance of both the samples was measured at room temperature after exposure to different toluene concentrations in the range 0.1 - 5 ppm. Figs. 1a and 1b show the sensor responses for both NC1 and NC2 samples. Each toluene exposure time lasted for 5 minutes, followed by a 25 min recovery period under dry air.

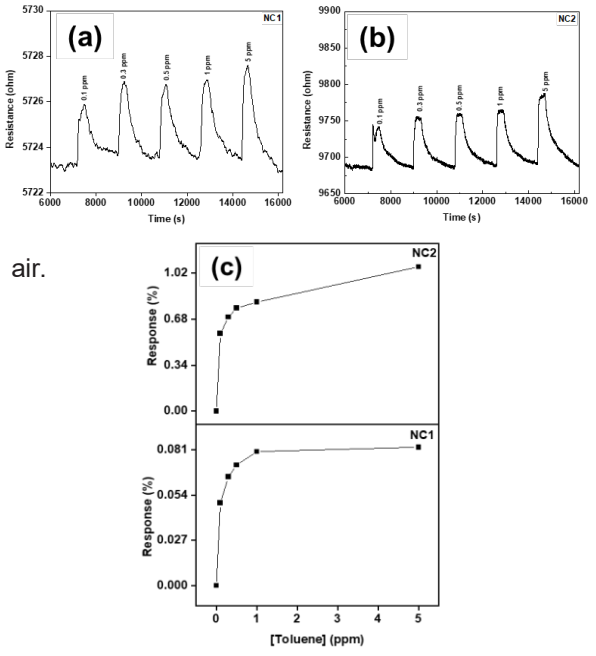

Fig. 1. Dynamic response plots of rGO/SnO_2 aerogel samples (a) NC1 (b) NC2 at different concentrations of toluene. Plot between sensor response % and concentration of toluene.

The sensor response is defined using the following equation.

$$Response\ (\%) = \frac{R_g - R_a}{R_a} * 100 \qquad (1)$$

Where R_a is the stable resistance value measured in ambient air and R_g is the resistance measured in the target gas, toluene.

The testing results showed that the resistance of both samples increased with rising toluene concentrations, indicating the overall p-type semiconducting nature of the samples with surface doping. Between the two samples, NC2 exhibited a higher response % to toluene than NC1 across the measured concentration range and the respective values are given in Table 1.

Tab. 1: Calculated sensor response % values for both the samples at diff. concentrations of toluene

PPM	Response (%) NC1	Response (%) NC2
0.1	0.04942	0.57302
0.3	0.06488	0.69578
0.5	0.07186	0.76117
1	0.07991	0.80682
5	0.08256	1.06806

The better response of NC2 than NC1 is attributed to the washing process that removes residual precursors and crosslinking agents that negatively impact sensitivity. Further investigations into the effects of humidity and temperature on the aerogel sensor response, along with studies on cross-sensitivity and long-term stability, are currently underway. The complete results will be presented at the conference.

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Acknowledgements

This research was supported by the Engineering and Physical Sciences Research Council grant EP/W024284/1