Screen Printed $BaTiO_3$ for CO_2 Gas Sensor

Fabien Le Pennec, Sandrine Bernardini, Mohamad Hijazi, Carine Perrin-Pellegrino, Khalifa Aguir and Marc Bendahan
Aix Marseille Univ, Université de Toulon, CNRS, IM2NP, Marseille, France
e-mails: {fabien.lepennec, sandrine.bernardini, mohamad.hijazi, carine.perrin-pellegrino, khalifa.aguir, marc.bendahan} @im2np.fr

Abstract—**In this work, we report on a new evaluation of metal oxide based on carbon dioxide sensors, using barium titanate nano-powder. The sensing principle is based on a change in conductance of semiconducting oxides when carbon dioxide is present. The sensitive layer was deposited on a SiO_2/Si substrate by screen printing technology. The sensor responses were studied between 100 and 5000 ppm of carbon dioxide in the air with 50% relative humidity. The sensor presents good sensitivity toward carbon dioxide, with a stable baseline, and fast response and recovery time. These results are promising for carbon dioxide sensing.**

Keywords-Gas Sensor; CO_2; $BaTiO_3$; Metal Oxide; Environment.

I. INTRODUCTION

Carbon dioxide (CO_2) is one of the main gases responsible for the greenhouse effect and, consequently, the global warming trends. Hence, its monitoring is subject of a major societal challenge. With an outdoors concentration up to 500 ppm in urban areas, the ventilation balance is affected and the development of reliable low-cost CO_2 sensors at multiple sites becomes an industrial strategy. Nowadays, the most commonly used method to detect CO_2 is based on optical sensors. Despite their efficiency in CO_2 detection, these technologies are expensive, have high electric consumption and are not fully miniaturized. Metal oxide gas sensors show potential features such as low-cost, mass production, miniaturization, fast response and recovery times.

In 1991, Ishihara et al. [1] first proposed a composite material based on p and n-type semiconductors, by mixing copper oxide (CuO) and barium titanate ($BaTiO_3$) powders. In 2001, Liao et al. [2] showed that pure CuO and pure $BaTiO_3$ gave no response to CO_2. Since then, these pure materials have been definitively abandoned and only composites have been studied. But, the sensors of Liao et al. [2] were in the very basic form of large discs of sintered powders with unknown granularity, connected by Ag paste electrodes. Thus, we propose herein a new evaluation of $BaTiO_3$ based CO_2 sensors.

The rest of the paper is structured as follows. In Section II, we describe our approach based on $BaTiO_3$ nano-powder deposition on platinum interdigitated electrodes by screen printing, a low cost, and an easily used technique. Then, in Section III, the sensing results are discussed based on a change in conductance of $BaTiO_3$ when CO_2 are introduced. Finally, a conclusion is given in Section IV.

II. DESCRIPTION OF APPROACH AND TECHNIQUES

This description is composed of two parts; one is the sensing film fabrication; the other is the measurement system set-up.

A. *Gas sensors*

Our gas sensor is made of Ti/Pt interdigitated electrodes (5 and 100 nm, respectively) deposited on Si/SiO_2 by magnetron sputtering. $BaTiO_3$ thick films were deposited by screen printing on these electrodes to produce a CO_2 sensitive layer. $BaTiO_3$ nano-powder (<100 nm, 4 g) was mixed with glycerol (1.5 g) and screen printed on Si/SiO_2 substrate with interdigitated platinum electrodes spaced by 50 µm (Figure 1).

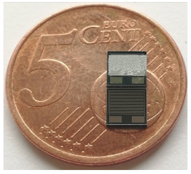

Figure 1. Sample image of SiO_2/Si substrate (4 x 4 mm^2) with platinum electrodes (bottom) and the final sensor with the $BaTiO_3$ thick film (top).

The deposited film was annealed at 400°C on a hotplate, in ambient air. The film structure was determined by X-Ray Diffraction (XRD) with a Philip’s X’Pert MPD equipment (λ = 1.54 Å).

B. *Setup*

0.1 V DC voltage was applied to the sample while the electrical resistance was monitored by a homemade LabVIEW program using a Keithley Model 2450 Source Measure Unit (SMU) Instrument (Keithley, U.S.A.). Dry air (no humidity) was used as both the reference and the carrier gas. A gas dilution and humidification system generates an output mixture at the target CO_2 concentrations (1 to 5000 ppm) with a variable humidity (0% to 90%). The sensing properties of $BaTiO_3$ sensors were tested by measuring the sensor resistance for 5 min under CO_2 diluted in dry air and in humid air with a standard Relative Humidity (RH) value of 50 %. The sensors were operated at several temperatures from 200°C to 300°C on a hotplate. A constant total flow was maintained at 500 Standard Cubic Centimeters per Minute (SCCM) via mass flow controllers.

III. RESULTS AND DISCUSSIONS

The XRD diffractogram of $BaTiO_3$ thick film (Figure 2) shows the presence of $BaTiO_3$ nanocrystals in the tetragonal phase of $BaTiO_3$ [3].

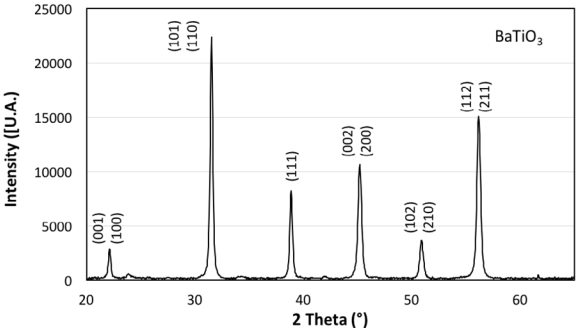

Figure 2. $BaTiO_3$ diffractogram using λ = 1.54Å (Philip's X'Pert MRD).

The $BaTiO_3$ sensors for different CO_2 concentrations provide a measurable response depending on the CO_2 concentrations in the 100 - 5 000 ppm range and 50% RH at various temperatures. The higher response amplitude variations were obtained at 280°C. Figures 3 and 4 show, respectively, the response and the sensitivity of the $BaTiO_3$ sensor under CO_2 in the air with 50% RH at 280 °C, the optimum working temperature. It gives reversible responses to CO_2 concentrations between 100 ppm and 5000 ppm.

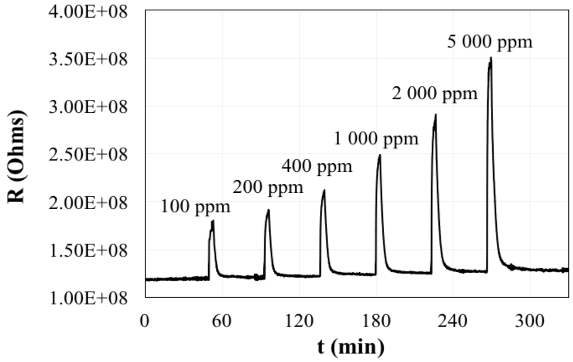

Figure 3. Resistive responses of $BaTiO_3$ to six CO_2 concentrations with 50% RH at 280°C.

The sensor response is defined in (1) as the ratio between the sensor resistance under CO_2 exposure and the sensor resistance in the air:

$$R = R_{gas} / R_{air} \qquad (1)$$

where R_{air} is the sensor resistance through humid airflow and R_{gas} the sensor resistance in the presence of CO_2.

The response time was less than 2 minutes and the recovery time was about 5 minutes. The responses are proportional to the CO_2 concentrations, and they restored the original baseline in less than 5 minutes.

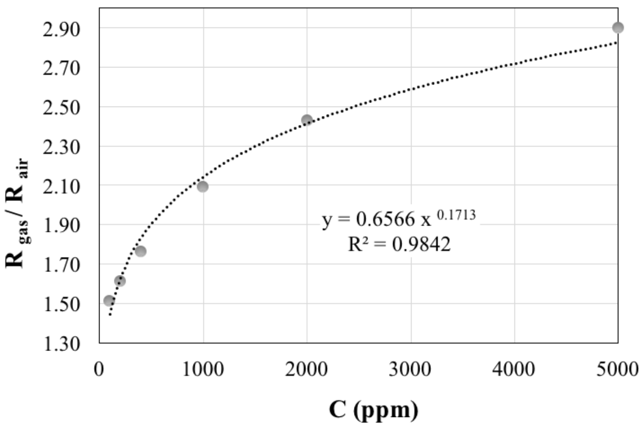

Figure 4. Sensitivity response of $BaTiO_3$ to different concentrations of CO_2 with 50% RH at 280°C.

These results are in agreement with the recent review on chemiresistive CO_2 gas sensors [4].

IV. CONCLUSIONS

This work reported preliminary results on a screen printing $BaTiO_3$ sensor working at an optimum temperature of 280°C and for 50% RH. Our experiments showed stable baseline responses with fast response/recovery times towards CO_2. These sensors seem promising for measuring indoor and outdoor air quality and for CO_2 detection. However, after a few weeks, using the same operational conditions, the sensor responses were weakened on the record. New experiments and analyses are in progress to understand this phenomenon.

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