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## Screen Printed BaTiO<sub>3</sub> for CO<sub>2</sub> Gas Sensor

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**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<sub>2</sub>/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<sub>2</sub>; BaTiO<sub>3</sub>; Metal Oxide; Environment.

### I. INTRODUCTION

Carbon dioxide (CO<sub>2</sub>) 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<sub>2</sub> sensors at multiple sites becomes an industrial strategy. Nowadays, the most commonly used method to detect CO<sub>2</sub> is based on optical sensors. Despite their efficiency in CO<sub>2</sub> 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<sub>3</sub>) powders. In 2001, Liao et al. [2] showed that pure CuO and pure BaTiO<sub>3</sub> gave no response to CO<sub>2</sub>. 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<sub>3</sub> based CO<sub>2</sub> sensors.

The rest of the paper is structured as follows. In Section II, we describe our approach based on BaTiO<sub>3</sub> 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<sub>3</sub> when CO<sub>2</sub> 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<sub>2</sub> by magnetron sputtering. BaTiO<sub>3</sub> thick films were deposited by screen printing on these electrodes to produce a CO<sub>2</sub> sensitive layer. BaTiO<sub>3</sub> nano-powder (<100 nm, 4 g) was mixed with glycerol (1.5 g) and screen printed on Si/SiO<sub>2</sub> substrate with interdigitated platinum electrodes spaced by 50 μm (Figure 1).

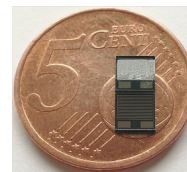


Figure 1. Sample image of SiO<sub>2</sub>/Si substrate (4 x 4 mm<sup>2</sup>) with platinum electrodes (bottom) and the final sensor with the BaTiO<sub>3</sub> thick film (top).

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 ( $\lambda = 1.54 \text{ \AA}$ ).

#### 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<sub>2</sub> concentrations (1 to 5000 ppm) with a variable humidity (0% to 90%). The sensing properties of BaTiO<sub>3</sub> sensors were tested by measuring the sensor resistance for 5 min under CO<sub>2</sub> 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<sub>3</sub> thick film (Figure 2) shows the presence of BaTiO<sub>3</sub> nanocrystals in the tetragonal phase of BaTiO<sub>3</sub> [3].

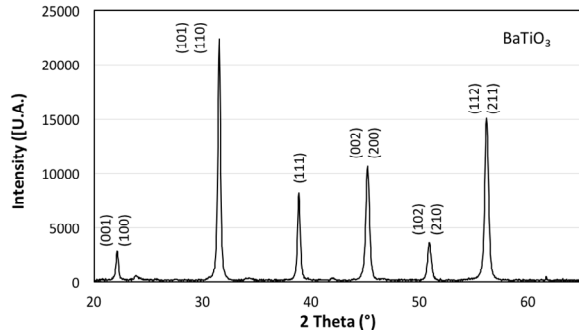


Figure 2. BaTiO<sub>3</sub> diffractogram using  $\lambda = 1.54\text{\AA}$  (Philip's X'Pert MRD).

The BaTiO<sub>3</sub> sensors for different CO<sub>2</sub> concentrations provide a measurable response depending on the CO<sub>2</sub> 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<sub>3</sub> sensor under CO<sub>2</sub> in the air with 50% RH at 280 °C, the optimum working temperature. It gives reversible responses to CO<sub>2</sub> concentrations between 100 ppm and 5000 ppm.

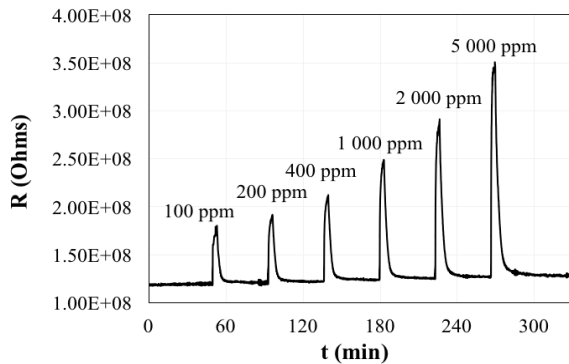


Figure 3. Resistive responses of BaTiO<sub>3</sub> to six CO<sub>2</sub> concentrations with 50% RH at 280°C.

The sensor response is defined in (1) as the ratio between the sensor resistance under CO<sub>2</sub> exposure and the sensor resistance in the air:

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

where R<sub>air</sub> is the sensor resistance through humid airflow and R<sub>gas</sub> the sensor resistance in the presence of CO<sub>2</sub>.

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

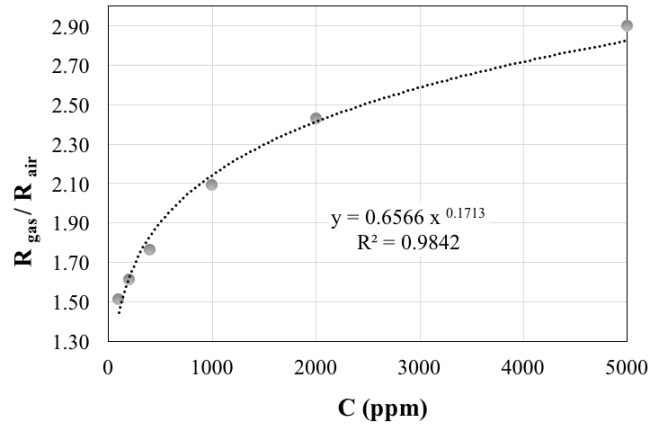


Figure 4. Sensitivity response of BaTiO<sub>3</sub> to different concentrations of CO<sub>2</sub> with 50% RH at 280°C.

These results are in agreement with the recent review on chemiresistive CO<sub>2</sub> gas sensors [4].

IV. CONCLUSIONS

This work reported preliminary results on a screen printing BaTiO<sub>3</sub> 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<sub>2</sub>. These sensors seem promising for measuring indoor and outdoor air quality and for CO<sub>2</sub> 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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