

Gas-Sensing Properties of Sprayed Films of $(\text{CdO})_x(\text{ZnO})_{1-x}$ Mixed Oxide

R. Ferro, J. A. Rodríguez, I. Jiménez, A. Cirera, J. Cerdà, and J. R. Morante

Abstract—A novel NO_2 sensor based on $(\text{CdO})_x(\text{ZnO})_{1-x}$ mixed-oxide thin films deposited by the spray pyrolysis technique is developed. The sensor response to 3-ppm NO_2 is studied in the range 50 °C–350 °C for three different film compositions. The device is also tested for other harmful gases, such as CO (300 ppm) and CH_4 (3000 ppm). The sensor response to these reducing gases is different at different temperatures varying from the response typical for the p-type semiconductor to that typical for the n-type semiconductor. Satisfactory response to NO_2 and dynamic behavior at 230 °C, as well as low resistivity, are observed for the mixed-oxide film with 30% Cd. The response to interfering gas is poor at working temperature (230 °C). On the basis of this study, a possible sensing mechanism is proposed.

Index Terms—Gas sensor, mixed oxide, NO_2 , spray pyrolysis.

I. INTRODUCTION

A IR-QUALITY monitoring has received a great deal of attention in the last years. Nitrogen dioxide (NO_2) is one of the main harmful gases, which provokes noxious effects on environment and human health. Resistive-type sensors based on metal-oxide semiconductors have been intensively studied in the last decades due to the low cost, technological simplicity, small size, and ease of handling. Besides, thin-film gas sensors show high performance features such as high stability and fast response [1]–[3]. Furthermore, the compatibility with micromachined structures allows sensor miniaturization, reduction of the production cost, and power consumption.

Several metal oxides have been tested for NO_2 detection, tungsten trioxide (WO_3) being one of the most promising materials in view of its high sensitivity. However, thin films of this oxide generally exhibit high resistivity, which is the main drawback of sensors based on this material [4]. It is well known that the resistivity of the n-type semiconductor increases upon exposure to oxidizing gases like NO_2 . High-output sensor impedance is undesirable since a complex electronic circuit would be required in this case, thus complicating the construction of a portable miniaturized device.

Zinc oxide (ZnO) was the first metal oxide used for chemical sensors [5], but thin films of this material also have a high resistivity. On the contrary, as-deposited cadmium oxide (CdO)

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films exhibit low electrical resistivity and, consequently, sensing properties of ZnO might be modulated by mixing it with CdO in adequate proportions. In fact, the advantages of mixed oxides for gas detection has recently been discussed in literature [6] because of the possibility of combining the best sensing properties of pure components. Some reported results confirm this postulate. Indeed, multilayer structures formed by deposition of cadmium oxide on tin dioxide (SnO_2) were reported by Sberveglieri *et al.* [6] as highly sensitive and selective nitrogen oxide (NO_x) sensors. Additionally, different researchers [7]–[10] improved the sensing properties (sensitivity, selectivity, and recovery time) by adding CdO to iron oxide-based sensing materials.

In this context, our work deals with gas-sensing properties of thin films of $(\text{CdO})_x(\text{ZnO})_{1-x}$ mixed oxide for NO_2 detection. In addition, the sensor response to other interfering gases such as CO and CH_4 is also examined. Spray pyrolysis technique was selected to prepare the oxide films since it is an inexpensive and simple technique, which allows obtaining a wide range of nanostructured oxides with high surface area. A detailed study on the possibility of this technique for gas sensor has recently been reported by Korotchenkov *et al.* [11]. It has also been successfully used to deposit $(\text{CdO})_x(\text{ZnO})_{1-x}$ thin film for solar cells applications [12].

II. EXPERIMENTAL

Two solutions (0.1 M) were prepared using nitrates of Zn and Cd diluted in distilled water. Different compositions for the starting solutions were investigated (see Table I for the corresponding denomination of the samples). The resulting solution was sprayed onto alumina substrates having interdigitated Pt electrodes (length = 1.6 mm and width of spacing = 0.2 mm) on the front side and a Pt heating resistor on the bottom. Other technological parameters used were substrate temperature 130 °C, solution flow 3 ml/min, carrier gas flow (nitrogen) 5 l/min, and nozzle height 0.3 m. The details concerning the experimental setup can be found elsewhere [14]. All as-deposited $(\text{CdO})_x(\text{ZnO})_{1-x}$ films were subsequently annealed in static air at 600 °C for 2 h in order to stabilize the sensing properties.

The layer thickness was measured by means of a profilometer DEKTAK 3030. Energy-dispersive X-ray spectroscopy (EDS) analysis was used to determine the chemical composition at several points of the layers. The spectra were analyzed with ZAF software and the results were averaged for each layer. Gas-sensing tests were carried out in a stainless-steel chamber under a dynamic regimen. The chamber volume was 200 ml, and the total gas flux was fixed at 200 ml/min. The gas composition

TABLE I
RATIO OF THE ATOMIC PERCENT OF Cd WITH REGARD TO THE SUM
OF THE ATOMIC PERCENT OF Zn AND Cd IN THE SAMPLES

Sample	Cd nominal concentration (x)	Cd experimental concentration (x)
ZC1	0.15	0.14
ZC2	0.30	0.28
ZC3	0.50	0.52

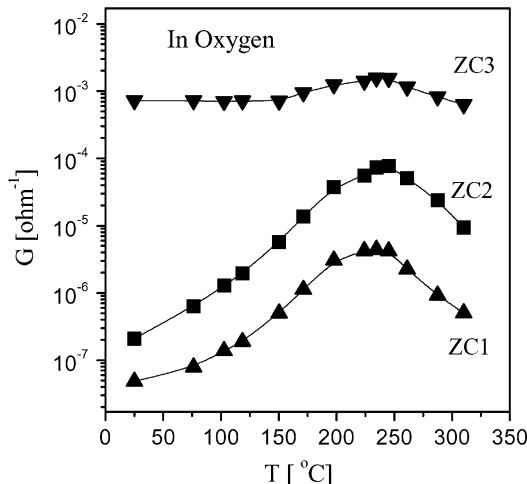


Fig. 1. Dependence of conductance on sensor temperature, in oxygen, for $(\text{CdO})_x(\text{ZnO})_{1-x}$ films with different compositions according to Table I (ZC1 : $x = 0.14$, ZC2 : $x = 0.28$, and ZC3 : $x = 0.52$).

was regulated by mixing the target gas and synthetic air, coming from the certified bottles, in appropriate proportions by means of a mass flow controller (MFC). Automatic control of MFC, as well as measurements of electrical parameters, were performed with the help of a PC by using data acquisition boards. Further details can be found elsewhere [13].

III. RESULTS AND DISCUSSION

Mixed-oxide layers having thickness values in the interval of 400–500 nm were obtained. Such thickness was considered optimal to avoid the usual increase of resistance in ultrathin sensors, but keeping the main properties of thin layers. From X-ray patterns, it was established that the films are constituted of a mixture of cubic CdO and hexagonal ZnO phases [15]. Table I shows the EDS data corresponding to film composition. The atomic percent of Cd is considered with respect to the sum of the atomic percent of Zn and Cd in the samples and corresponds to the x value in the formula $(\text{CdO})_x(\text{ZnO})_{1-x}$. As can be observed, there is a good correspondence between those values of x estimated from the composition of the sprayed solution (nominal values) and those calculated from the experimental data.

Fig. 1 depicts the temperature variation of the conductance of the films exposed to oxygen. It should be noted that, in all cases, the conductance increases as temperature increases and a maximum value is reached in the temperature range 200 °C–230 °C. The initial increase of the conductance below

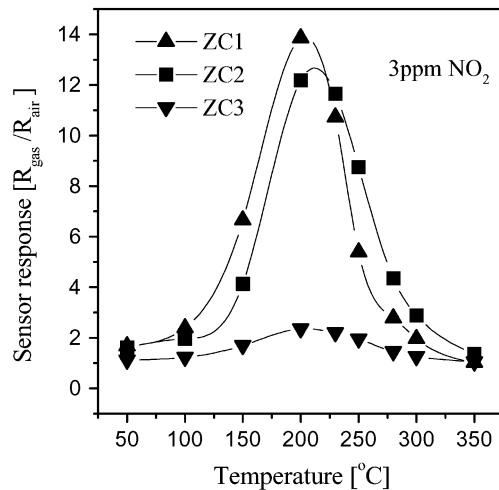
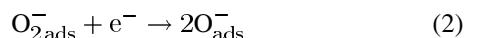


Fig. 2. Effect of temperature on sensor response to 3-ppm NO_2 for $(\text{CdO})_x(\text{ZnO})_{1-x}$ films with different compositions according to Table I (ZC1 : $x = 0.14$, ZC2 : $x = 0.28$, and ZC3 : $x = 0.52$).

230 °C can be related with the typical semiconductor behavior, that is, an increase of the electron concentration is produced by thermal excitation of the valence electrons. The ulterior behavior observed in Fig. 1, to a great extent, reveals a typical surface-controlled sensor model [16], which has been applied for SnO_2 films as well as for CdO-doped Fe_2O_3 [8] and ZnFe_2O_4 [10] films. It is known that at low temperatures, the surface is populated by physisorbed and chemisorbed species such as O_2^- , OH^- , and H_2O while, at higher temperatures (above 300 °C), the ions O^- and O^{2-} predominate [17], [18]. The maximum observed for the sensor response in our experiments might be associated with the occurrence of the following reactions as temperature increases [10]



where subscripts “gas” and “ads” refer to species in gaseous phase and adsorbed on the film surface, respectively. It seems that at temperatures higher than 200 °C, the effect of these reactions is more significant than the thermal excitation and the conductivity finally decreases due to capture of electrons, thus diminishing their concentration in the conduction band.

The explained behavior also predicts the response of the material to the presence of oxidizing gases, which results in an increase of the resistance. Fig. 2 depicts the sensor response to NO_2 measured in the temperature interval 50 °C–350 °C for the three different samples studied. The sensor response (S) in our case is defined as the resistance ratio $R_{\text{gas}}/R_{\text{air}}$, R_{gas} , and R_{air} being the sensor resistance in presence of the target gas and air, respectively. The gas concentration was fixed at 3 ppm since it is the concentration listed in the safety standard by American Conference of Governmental Industrial Hygienist (ACGIH). It is observed that the sensor resistance rises in presence of NO_2 for all temperatures and a well-defined maximum on sensor response is achieved at about 200 °C. A somewhat similar result was reported by Leo *et al.* for sprayed SNO_2 film-based sensors [19]. The observed behavior may be understood by considering that the kinetic of the surface interaction is thermally ac-

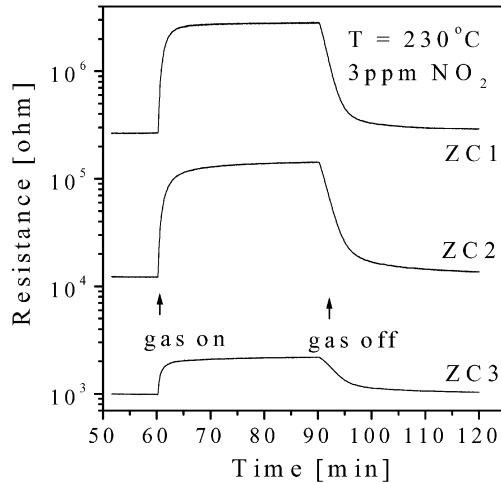
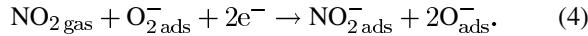
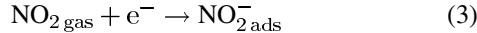
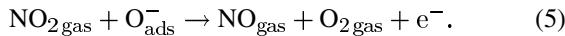


Fig. 3. Time resistance variation of $(\text{CdO})_x(\text{ZnO})_{1-x}$ films with different compositions, at 230 °C, when exposed to 3-ppm NO_2 (ZC1 : $x = 0.14$, ZC2 : $x = 0.28$, and ZC3 : $x = 0.52$).

tivated and determined by the concurrence of several processes of adsorption, reaction, and desorption of previously adsorbed molecules of NO_2 . At temperatures below 200 °C, the sensor response change might be attributed mainly to the adsorption and/or reaction of NO_2 molecules on the solid surface according to the following mechanisms [20]:



These processes reduce the electron concentration in the conduction band with a corresponding increase in sensor response. On the other hand, if temperature increases, the following reaction might take place even though the concentration of O_2^-ads at temperatures below 300 °C might still be low [21]



It seems that the decrease of adsorption rate together with the possible desorption of some adsorbed molecules of NO_2 and the occurrence of the reaction (5) lead to a decrease in the sensor response at temperature higher than 200 °C, as observed in the experimental results.

According to Fig. 2, the maximum sensor response is obtained at around 200 °C (sample ZC1). However, the working temperature was fixed at 230 °C by making a compromise between sensor response and dynamic characteristics (response and recovery times), which are derived from a time resistance variation, as shown in Fig. 3. This dependence was obtained at 230 °C, by exposing the samples for 30 min to dry air, 3 ppm of NO_2 , and dry air, alternatively. No drift of the baseline was observed. It should be noted that the higher the CdO content of the sample, the lower the measured resistance.

As can be observed from Figs. 2 and 3, at working temperatures, the response of sample ZC2 is slightly higher and its electrical resistance is lower than the corresponding values for sample ZC1. It seems that CdO affects not only the sensor transducer function, but also its recognition function. That is, its role could be related with the transformations of chemical signal into an electrical one and also with the recognition or identification

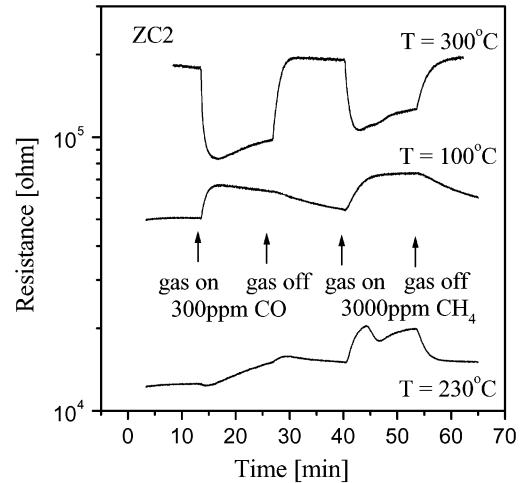


Fig. 4. Variation in time of electrical resistance of sample ZC2 ($x = 0.28$) at different temperatures when exposed to 300-ppm CO and 3000-ppm CH_4 . The curve corresponding to the resistance measured at 300 °C was separated for clarity.

of gas molecule. This effect might be a result of the formation of extrinsic defects, which act as reactive sites. Anyway, the role of the CdO in the recognition function is not clear yet and a more detailed study is required.

In order of evaluate the sensor response to other typical harmful gases present in the atmosphere, the samples were exposed to 300 ppm of CO and 3000 ppm of CH_4 , at three different temperatures. These values of concentrations are higher than those corresponding to the first alarm threshold limit for these gases according to the regulations of ACGIH. Fig. 4 shows the corresponding resistance transient for the sample ZC2. An interesting result is observed: for both gases, at low temperature (100 °C), an increase of the sensor resistance is observed, corresponding to an oxidizing reaction of molecules adsorbed on the film surface, whereas at high temperature (300 °C), a contrary effect is manifested. At intermediate temperatures, a transitory process occurs. This phenomenon evidences the presence, in this material, of several concurrent sensitivity mechanisms thermally activated. It is known that the oxidizing or reducing character of a gas in contact with an oxide metal semiconductor depends on the gas pressure, surface temperature, kind of species adsorbed on the surface, and other morphological, structural, and electronic factors which determine the concentration of surface active sites of adsorption and surface catalytic activity. It has been reported about the oxidizing character of nitrous oxides (NO and NO_2) in contact with samples of SnO_2 [20]. However, the same interactions have produced an increase or decrease of the sensor resistance, depending on the temperature range and gas concentration [21].

In our case, a somewhat similar situation might be taking place. The rise of the resistance of the sensor upon exposure to CO and CH_4 observed at temperatures as low as 100 °C might be attributed to the reaction of the gas molecules with the ionosorbed oxygen according to the following possible reactions:



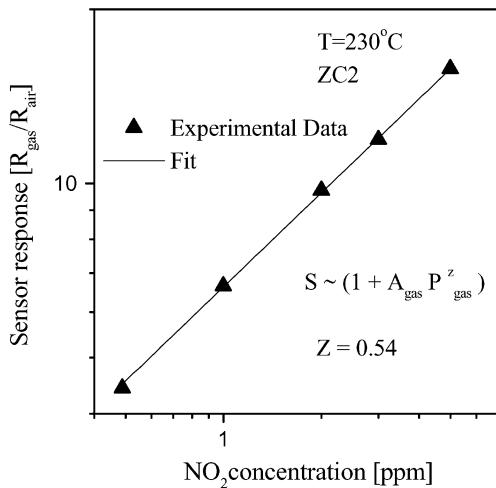
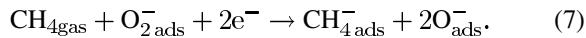
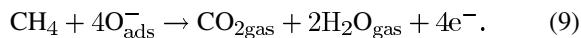
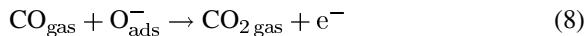


Fig. 5. Dependence of sensor response on NO_2 concentration at 230°C for sample ZC2 ($x = 0.28$).



These interactions provoke an increase of the sensor resistance due to a decrease of the free electron concentration. The proposed mechanisms have an empirical character and have not been inferred from *in situ* measurements; however, they seem to be reasonable in our material.

At higher temperatures, the interaction with the ionosorbed species $\text{O}_2^-_{\text{ads}}$ is likely to occur following the reactions [22]:



It is worth mentioning that at 230°C (working temperature), the response to CO and CH_4 are about one order of magnitude lower than response to NO_2 ($S_{\text{CO}} = 1.26$ and $S_{\text{CH}_4} = 1.31$). This fact indicates the possibility to design a selective sensor, which constitutes one of the major goals in semiconductor gas-sensor technology.

The response to nitrogen dioxide follows the standard power dependence, as displayed in Fig. 5. Gurlo *et al.* [23] have proposed an adsorption model to analyze the sensor response of In_2O_3 and MoO_3 - In_2O_3 exposed to O_3 and NO_2 . Considering the presence, on the surface, of states created by the target gas (NO_2 in our case), in addition to the states originated from the ionosorbed oxygen species, a simple equation for the sensor response (S) was deduced by the authors

$$S \sim (1 + A_{\text{gas}} P^z_{\text{gas}}) \quad (10)$$

where $Z = f/a$, a is the number of atoms of the target molecule, f describes the form (molecular or atomic) in which the gas is adsorbed, A_{gas} is a reaction constant which depends on the nature of the system gas-material, and P is the partial gas pressure. The fit of our experimental data (Fig. 5) by using (10) leads to a value $z = 0.54$. According to the postulated model, an exponent equal to 0.5 should be obtained when ionosorbed oxygen species O_2^- result from the reaction. Therefore, we may conclude that the main sensing mechanism of $(\text{CdO})_x(\text{ZnO})_{1-x}$

mixed oxide under NO_2 is associated to reaction (4) with a further dissociation of the NO_2^- according to the reaction proposed in [21]



Of course, the process described by reaction (3) might also take place under the same suppositions. The dissociation of adsorbed NO_2 molecules on In_2O_3 film surface was confirmed in [23] by analyzing O 1 s and N 1 s core level signals in XPS spectra.

IV. CONCLUSION

A novel NO_2 gas sensor based on $(\text{CdO})_x(\text{ZnO})_{1-x}$ mixed-oxide thin films deposited by spray pyrolysis has been studied. The sensor follows a typical surface-controlled gas-sensing model. A different behavior was observed when the sensor surface was exposed to reducing gases at different temperatures. Thus, the sensor resistance increases at low temperature (100°C), while it decreases at high temperature (300°C) as a consequence of different surface interaction mechanisms.

The dependence of sensor response on the test gas concentration follows a power law with an exponent equal to 0.54, which allowed us to propose a possible gas-sensing mechanism at working temperature. A device with 30% Cd exhibits satisfactory sensor properties to 3-ppm NO_2 .

REFERENCES

- [1] S. G. Ansari, P. Boroojerdian, S. K. Kulkarni, S. R. Sainkar, R. N. Karekar, and R. C. Aiyer, "Effect of thickness on H_2 gas sensitivity of SNO_2 nanoparticles-based thick film resistors," *J. Mater. Sci.*, vol. 7, pp. 267–270, 1996.
- [2] B. Fliettner and I. Eisele, "Work function measurements for gas detection using tin oxide layers with a thickness 1 and 200 nm," *Thin Solid Films*, vol. 250, pp. 258–262, 1994.
- [3] B. C. Tofield, "State of the art and future prospect for solid state gas sensors," in *Solid State Gas Sensors*, P. T. Moseley and B. C. Tofield, Eds. Bristol, U.K.: Adam Hilger, 1987, pp. 198–238.
- [4] T. Inoue, K. Ohtsuka, Y. Yoshida, Y. Matsuura, and Y. Kajiyama, "Metal oxide semiconductor NO_2 sensor," *Sens. Actuators B*, vol. 25, pp. 388–391, 1995.
- [5] T. Seiyama, A. Kato, K. Fujishiri, and M. Nagatoni, "A new detector for gaseous components using semiconductive thin film," *Anal. Chem.*, vol. 34, pp. 1052–1053, 1962.
- [6] K. Zakrzewska, "Mixed oxides as gas sensors," *Thin Solid Films*, vol. 391, pp. 229–238, 2001.
- [7] G. Sberveglieri, G. Groppelli, and P. Nelli, "Highly sensitive and selective NO_x and NO_2 sensor based on Cd-doped SNO_2 thin films," *Sens. Actuators B*, vol. 4, pp. 457–460, 1991.
- [8] X. Liu, Z. Xu, Y. Liu, and Y. Shen, "A novel high performance ethanol gas sensor based on $\text{CdO}-\text{Fe}_2\text{O}_3$ semiconducting materials," *Sens. Actuators B*, vol. 52, pp. 270–273, 1998.
- [9] Z. Tianshu, P. Hing, Y. Li, and Z. Jiancheng, "Selective detection of ethanol vapor and hydrogen using Cd-doped SNO_2 -based sensors," *Sens. Actuators B*, vol. 60, pp. 208–215, 1999.
- [10] C. Xiangfeng, L. Xingqin, and M. Guangyao, "Effects of CdO dopant on the gas sensitivity properties of ZnFe_2O_4 semiconductors," *Sens. Actuators B*, vol. 65, pp. 64–67, 2000.
- [11] G. Korotcenkov, V. Brinzari, and S. Dimitriev, "SNO₂ films for thin film gas sensor design," *Mater. Sci. Eng. B*, vol. 56, pp. 195–204, 1999.
- [12] O. Vigil, F. Cruz, G. Santana, L. Vaillant, A. Morales-Acevedo, and G. Contreras-Puente, "Influence of post-thermal annealing on the properties of sprayed cadmium-zinc oxide thin films," *Appl. Surf. Sci.*, vol. 161, pp. 27–34, 2000.
- [13] I. Jiménez, A. Cirera, J. Folch, A. Cornet, and J. R. Morante, "Innovative method of pulverization coating of prestabilised nanopowders for mass production of gas sensors," *Sens. Actuators B*, vol. 78, pp. 78–82, 2001.

- [14] A. Cirera, A. Cabot, A. Cornet, and J. R. Morante, "CO-CH₄ selectivity enhancement by *in situ* Pd-catalyzed microwave SNO₂ nanoparticles for gas detectors using active filter," *Sens. Actuators B*, vol. 78, pp. 151–154, 2001.
- [15] R. Ferro, J. A. Rodríguez, and P. Bertrand, "(ZnO)_x(CdO)_{1-x} mixed oxide film deposited spray pyrolysis from nitrate solutions," *J. Mater. Sci. Lett.*, vol. 21, pp. 1939–1941, 2002.
- [16] M. Nitta, S. Ontani, and M. Harodome, "Temperature dependence of resistivities of SNO₂ based gas sensors exposed to CO, H₂, and C₃H₈ gases," *J. Electron. Mater.*, vol. 9, 1980.
- [17] P. T. Moseley and D. E. Williams, "Oxygen surface species on semiconducting oxides," in *Solid State Gas Sensors*, P. T. Moseley and B. C. Tofield, Eds. Bristol, U.K.: Adam Hilger, 1987, pp. 46–53.
- [18] S. C. Chang, "Oxygen chemisorption on thin oxide: Correlation between electrical conductivity and EPR measurements," *Surf. Sci.*, vol. 86, pp. 335–344, 1979.
- [19] G. Leo, R. Rella, P. Siciliano, S. Capone, J. C. Alonso, V. Pankov, and A. Ortiz, "Sprayed SNO₂ thin films for NO₂ sensors," *Sens. Actuators B*, vol. 58, pp. 370–374, 1999.
- [20] I. Sayago, J. Gutiérrez, L. Arés, J. I. Robla, M. C. Horrillo, J. Getino, and J. A. Agapito, "The interaction of different oxidizing agents on doped tin oxide," *Sens. Actuators B*, vol. 24–25, pp. 512–515, 1995.
- [21] B. Ruhland, T. Becker, and G. Müller, "Gas-kinetic interactions of nitrous oxides with SNO₂ surfaces," *Sens. Actuators B*, vol. 50, pp. 85–94, 1998.
- [22] T. Becker, S. Ahlers, Chr. Bosch-v.Braunmühl, G. Müller, and O. Kiesewetter, "Gas sensing properties of thin- and thick-film tin-oxide materials," *Sens. Actuators B*, vol. 77, 2001.
- [23] A. Gurlo, N. Bârsan, M. Ivanovskaya, U. Weimar, and W. Göpel, "In₂O₃ and MoO₃-In₂O₃ thin films semiconductors sensors: Interaction with NO₂ and O₃," *Sens. Actuators B*, vol. 47, 1998.

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Dr. Morante received the research prize Narciso Monturiol from the Generalitat of Catalunya, Spain. He has also received the "Senior Research Distinction" prize from the Generalitat de Catalunya.