



Ozone gas sensor based on nanocrystalline SrTi_{1-x}Fe_xO₃ thin films

Valmor R. Mastelaro^{a,*}, Sérgio C. Zílio^a, Luis F. da Silva^a, Pedro I. Pelissari^a, Maria I.B. Bernardi^a, Jacques Guerin^b, Khalifa Aguir^b

^a Instituto de Física de São Carlos, Universidade de São Paulo, São Carlos CEP 13450-970, São Paulo, Brazil

^b IM2NP (UMR CNRS 6242), Université Paul Cezanne, FST St. Jérôme S152, 13397 Marseille, France

ARTICLE INFO

Article history:

Received 6 December 2012

Received in revised form 14 February 2013

Accepted 15 February 2013

Available online 27 February 2013

Keywords:

SrTi_{1-x}Fe_xO₃ thin films

Ozone gas sensor

Nanostructure

Electron beam evaporation

ABSTRACT

We report on the use of nanocrystalline SrTi_{1-x}Fe_xO₃ (STF) for sensing ozone gas. Amorphous thin films were evaporated by the electron-beam physical vapor deposition technique and then converted to a polycrystalline form, as shown by X-ray diffraction patterns, after ex situ annealing at a relatively low temperature (550 °C). The influence of the iron content on the microstructure was investigated by both scanning electron microscopy (SEM) and atomic force microscopy (AFM), which revealed that the surface roughness of the films increased slightly as the amount of iron increased. Electrical resistance measurements were carried out to determine the response of the films upon exposure to ozone and when compared to other oxide metal sensors, STF films can also be considered as good candidates for application as ozone gas sensors.

© 2013 Elsevier B.V. All rights reserved.

1. Introduction

Solid state sensors are attractive to monitor the environment and to control technological processes because of their high sensitivity, short response times, low cost, low weight, and low energy consumption [1,2]. Most solid state sensors for detecting reducing and flammable gases such as CO, H₂, and CH₄, are of the conductometric type and make use of ceramics or thick-film materials [2]. However, this methodology has been shown to be inefficient for detecting ozone gas because of its high activity and the need of large thicknesses of film sensors even with small grain size [2].

Detection of the exact amount of ozone present in the atmosphere is of great importance, since this gas is a strong oxidizing agent, which has both positive and negative effects in medicine and various technological processes [1,2]. Different materials have been studied for their potential application as ozone gas sensors [2–22]. For instance, *n*-type materials such as In₂O₃ [2–14] and WO₃ [15–17] thin films have received a great deal of attention during the past few years. In particular, nanocrystalline In₂O₃ films were able to detect ozone concentrations as low as 15 ppb and to operate at room temperature, making them promising for the realization of low energy consumption and low-cost devices [4,5].

Although not so studied as In₂O₃ and WO₃, a number of other materials were also shown to be suitable as ozone gas sensors. Amongst them, we may quote SnO₂ [18], hybrid SnO₂/SWNTs

thin layers [19], CuCrO₂ nanocrystals and microcrystals [20] and Cd_{1-x}Zn_xO [21]. Recently, G. Korotcenkov and B. K. Cho published a review of different types of sensors that could be used for ozone detection [2]. In particular, they compared the sensing behavior of two well studied conductometric sensors, SnO₂- and In₂O₃-based materials and came to the conclusion that SnO₂ is an acceptable material for ozone sensor fabrication because it presents a high sensitivity and stability, although it has some disadvantages in comparison with In₂O₃.

Perovskite-based compounds are interesting materials from the viewpoint of both fundamental and applied solid-state physics since their structures are very versatile and allow different and useful applications [22–28]. Among several perovskite-based compounds, SrTi_{1-x}Fe_xO₃ (STF) solid solution has recently attracted the attention of many researchers due to its potential as an oxygen gas and hydrocarbonates sensors for automotive emission control [22–28]. The addition of Fe₂O₃ to the SrTiO₃ crystal structure causes the replacement of some Ti⁴⁺ by Fe³⁺ ions, which can create different types of defects due to the difference in their oxidation states [25–29]. When a Fe³⁺ ion occupies the Ti⁴⁺ octahedral site, mobile oxygen vacancies (*V*_O) are formed in order to balance the electric charge. The introduction of a large amount of iron creates a relatively large concentration of defects [29].

STF systems in film form have mainly been studied with respect to the synthesis and electrical characterization after screen printing a paste prepared from STF powder onto a determined substrate [30–34]. This method, although simple, normally produces thick films with micrometer-sized particles, which requires a high temperature and a long heating period during the calcination process.

* Corresponding author. Tel.: +55 16 33739828.

E-mail address: valmor@ifsc.usp.br (V.R. Mastelaro).

To the best of our knowledge, there are no studies about the sensitivity of *p*-type $\text{SrTi}_{1-x}\text{Fe}_x\text{O}_3$ (STF) thin films to ozone gas. To fill this gap, the present work examines the sensitivity of nanostructured $\text{SrTi}_{1-x}\text{Fe}_x\text{O}_3$ ($0 \leq x \leq 0.15$) thin films obtained by the electron-beam physical vapor deposition (EB-PVD) process. The samples used as targets were prepared using the polymeric precursor method [35,36]. We also study the influence of the iron concentration on structural and morphological properties of thin films and use electrical characterization to check the sensitivity of the STF thin films to ozone gas.

2. Experimental details

Nanocrystalline $\text{SrTi}_{1-x}\text{Fe}_x\text{O}_3$ (STF) powder samples with different Fe concentration (7.5, 10.0 and 15.0 mol% Fe) were obtained by the polymeric precursor method [35,36]. The synthesis procedure is well described elsewhere [35]. After removing water and the organic compounds, the precursor powders of each sample were annealed in an alumina crucible at 700°C for 3 h in an electric furnace with air atmosphere.

STF thin films were evaporated in a Balzers BAK600 evaporator using as targets the powder samples prepared with the polymeric precursor method. The films were deposited on SiO_2/Si substrates containing 100 nm-thick platinum electrodes, which were imprinted on a sputtered Pt film using photolithography and lift off processes. The distance between the electrodes was 50 μm . 70 nm-thick STF samples were evaporated by keeping the substrates at around 50°C , with the oxygen pressure in the chamber kept around 2×10^{-4} mbar. During evaporation, the thicknesses were monitored with a quartz balance and at the end of the process we confirmed the thicknesses by means of an electron microscope image. In order to crystallize the samples, the as-deposited amorphous films were submitted to an ex situ annealing for 4 h at 500°C in an electric furnace with air atmosphere.

The crystalline structure of the STF thin films was investigated by X-ray diffraction (XRD) measurements (Rigaku Ultima) in a two-theta range from 10 to 80° with steps of 0.02° and scanning speed of 2°min^{-1} using Cu K radiation. The microstructural characteristics of the thin film surface were investigated using an atomic force microscope (Digital Instruments, Nanoscope IIIa) in contact mode. The film thicknesses were measured using a field emission scanning electron microscope (FE-SEM, Zeiss Supra 35) operating at 3 kV.

The gas sensing properties of STF thin films were investigated in a test chamber that allows controlling the sensor temperature under variable gas concentrations. Dry air was used both as a reference (baseline) and as a carrier gas at a constant total flow of $8.3 \text{ cm}^3/\text{s}$. The ozone (O_3) gas was generated by oxidizing oxygen molecules of dry air by a pen-ray UV lamp calibrated to give an O_3 concentration range between 0.03 ppm and 0.8 ppm. The dry air containing ozone was blown directly on the sensor placed on top a heated holder within the test chamber. The working temperature (T_{work}) of the sensor, ranging from room temperature to 400°C , was controlled by an external heater source based on a Hg lamp driven by a regulated power supply. The measurement started after the sample resistance achieved a steady value. The resistance change upon exposure to ozone was measured by recording the current at an applied constant dc potential $V = 50 \text{ mV}$ with an HP4140B Source/Pico-ammeter.

3. Results and discussion

3.1. Structural and microstructural characterization of STF powder and thin films

Fig. 1 shows the X-ray diffraction patterns of $x = 0.00, 0.075, 0.10$ and 0.15 target nanocrystalline powder samples heat-treated at

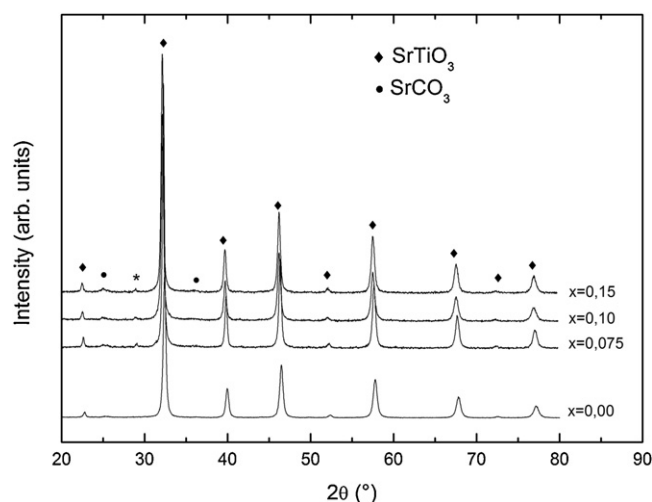


Fig. 1. XRD of SrTiO_3 ($x = 0.00$) and STF nanocrystalline powder samples heat treated at 700°C during 3 h.

700°C for 3 h. All patterns show well defined diffraction peaks corresponding to the STF solid solution with a cubic symmetry. For samples containing iron, the presence of low-intensity diffraction peaks was observed corresponding to the SrCO_3 phase. There was also a spurious peak around 28.8° due to a fluorescence effect. These results show that the STF samples used as targets for thin-film deposition do not present any crystalline phase containing iron.

Fig. 2 shows the XRD of the STF films after the ex situ annealing. The XRD pattern of SrTiO_3 ($x = 0.00$) thin film sample obtained at the same conditions is also shown in the figure. The peaks in the STF samples identified as belonging to the perovskite structure of SrTiO_3 phase (JCPDS: 35-0734) present a lower intensity, probably because of the film thickness (70 nm). We also observed an intense diffraction peak from the SiO_2/Si substrate, but no evidence of diffraction peaks related to iron oxide crystalline phases.

The influence of the iron concentration on the surface microstructure of STF films was analyzed by means of three-dimensional AFM images shown in Fig. 3. The images of the iron-doped samples depict microstructures that are homogeneous, rough, and uniform, with nanosized grains. The $x = 0.15$ sample shows an increase in the grain size probably due to a coalescence phenomenon, with the formation of pores between the grains. The mean surface roughness obtained from the AFM images show values of 1.4 nm, 5.6 nm, 8.4 nm and 9.2 nm for $x = 0.00, x = 0.075,$

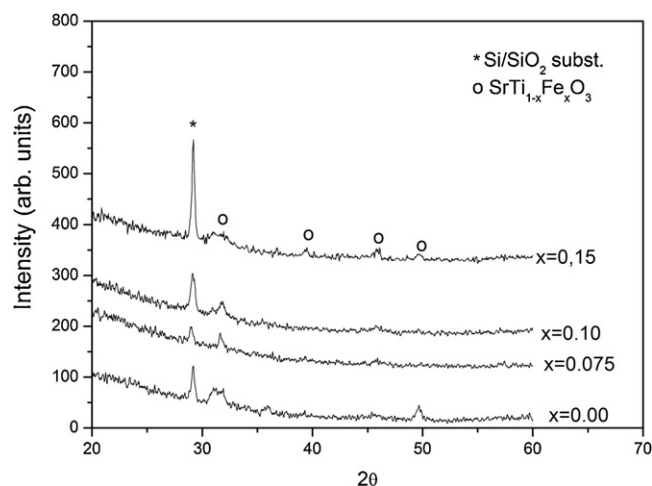


Fig. 2. XRD of 70 nm annealed thin films deposited on Si/SiO_2 substrates.

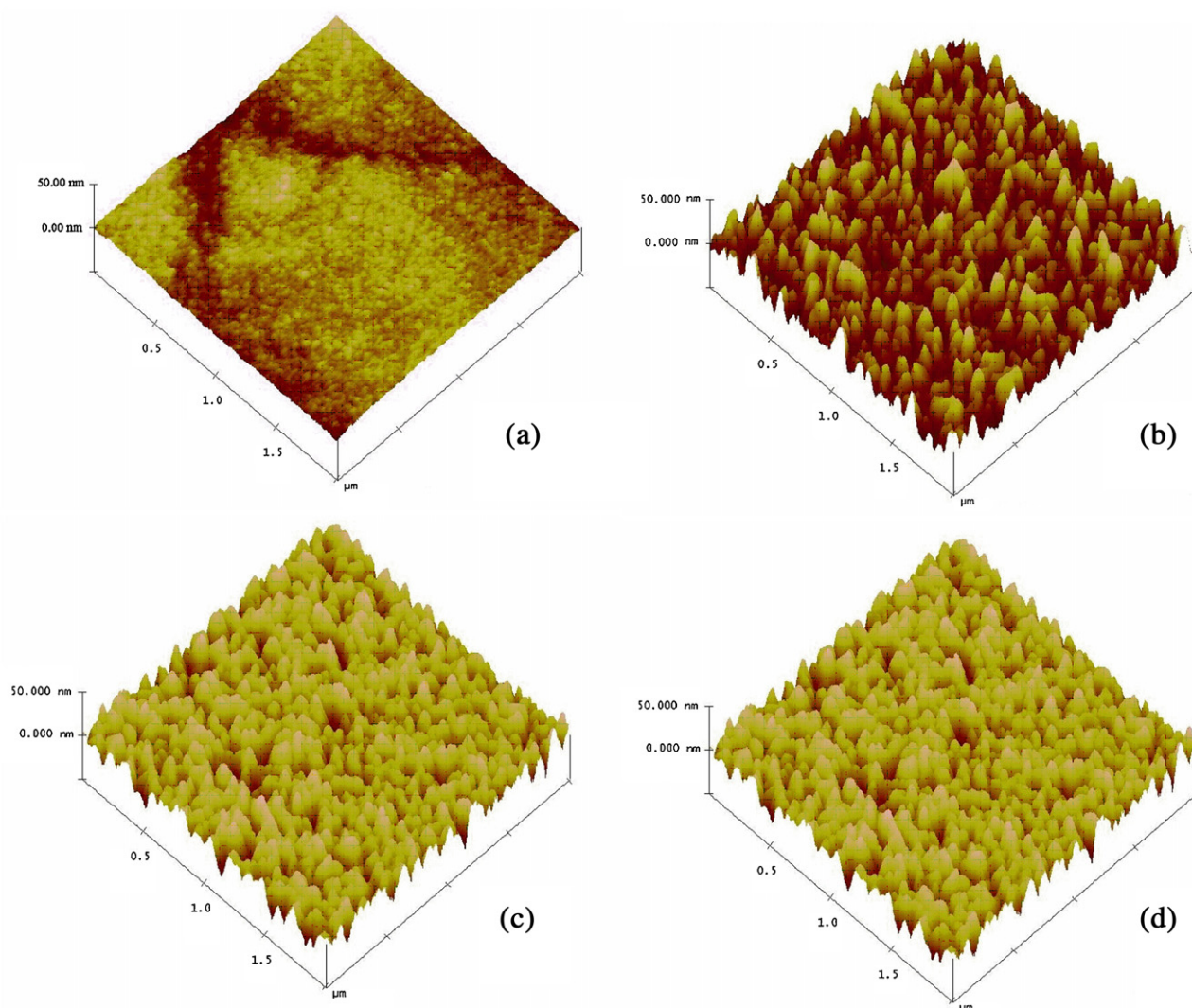


Fig. 3. AFM images of annealed thin film samples for (a) $x=0.00$, (b) $x=0.075$, (c) $x=0.10$ and (d) $x=0.15$.

$x=0.10$ and $x=0.15$, respectively. These results show that the increase of iron increases just slightly the surface roughness of the iron-doped STF samples.

3.2. Gas sensing characterization of STF thin films

Fig. 4 shows the resistance response of thin film samples $x=0.075$, $x=0.10$, and $x=0.15$ as a function of the ozone gas concentration and the work temperature. In the case of the $x=0.075$ and $x=0.10$ samples (Fig. 4(a) and (b)), the work temperature was fixed

at 250°C and the ozone concentration was varied. For the $x=0.15$ sample (Fig. 4(c)), the ozone concentration was fixed at 600 ppb whereas the temperature was varied between 190°C and 310°C . During each measurement cycle, the exposure time to the ozone gas was kept constant for 2 min ($x=0.075$ and $x=0.15$) and 3 min ($x=0.10$). As can be seen in Fig. 4, the samples show a *p*-type semi-conducting characteristic since their resistance decrease with the adsorption of oxidizing gases.

It is possible to observe from Fig. 4 that all samples have a good sensitivity to ozone, although we also observe a modification of the

Table 1
Comparison of the S values of STF samples and In_2O_3 - and WO_3 -based ozone sensors.

Sensors	Work temperature ($^{\circ}\text{C}$)	O_3 (ppb)	Response (S)	Reference
In_2O_3	300	100	1500	[37]
WO_3	250	30, 400, 800	16, 260, 310	[15]
STF				
$x=0.075$	250	75	3	
$x=0.075$	250	600	170–580	This study
$x=0.10$	250	600	10	
$x=0.15$	250	600	53	
$x=0.15$	220	600	267	
$x=0.15$	190	600	580	

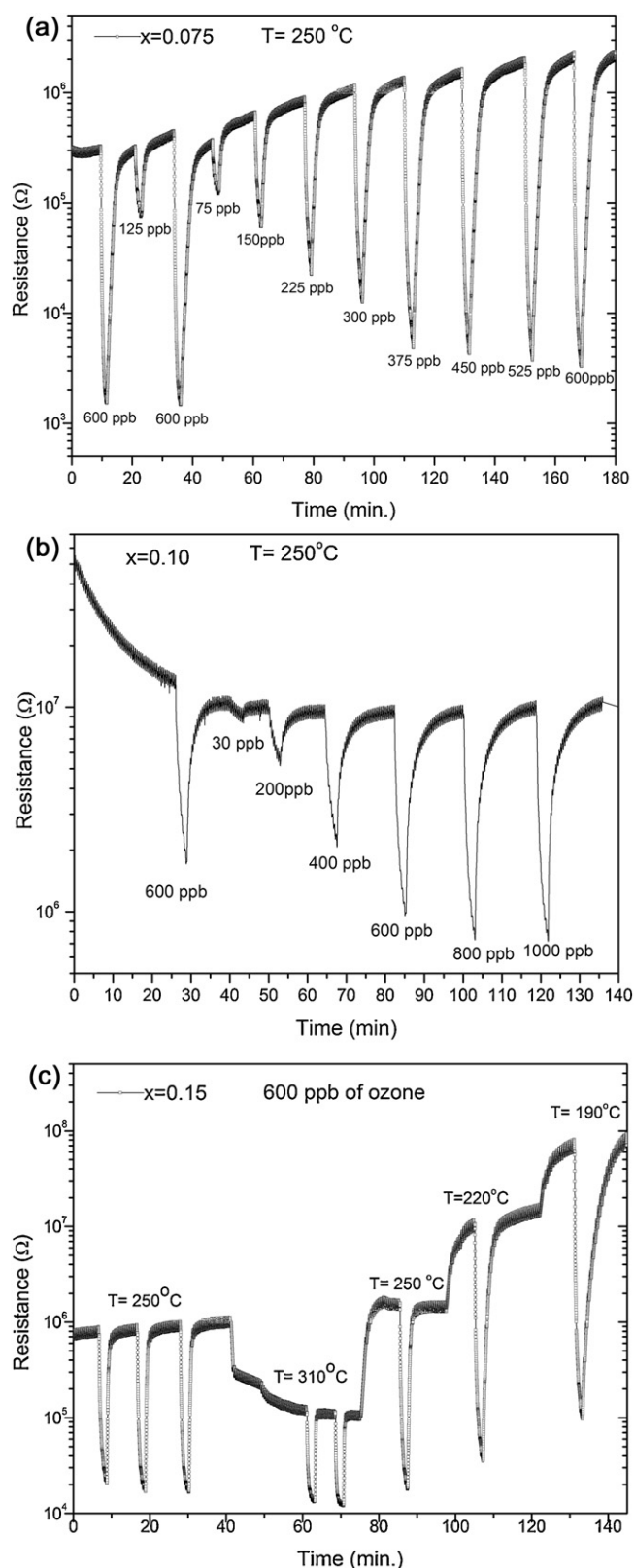


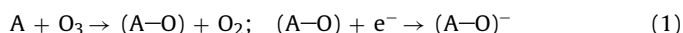
Fig. 4. Ozone gas response for: (a) $x=0.075$ (b) $x=0.10$ and (c) $x=0.15$ annealed samples as a function of ozone concentration and/or work temperature.

base line, mainly for the $x=0.075$ sample. The resistance changes by at least one order of magnitude when the thin films are exposed to 600 ppb of ozone. The response time is about 2 min and the recovery time is less than 5 min when exposed to 600 ppb, at a work temperature of about 250 °C. For the $x=0.075$ thin film, it was possible

to have a good resistance response when the sample was exposed to 75 ppb of ozone. We can also observe that for the $x=0.075$ and $x=0.10$ samples a saturation occurs when the amount of ozone are respectively higher than 525 and 800 ppb. In general, the response of oxides materials saturates when the concentration of the gas to be detected increases above a certain value. This effect is related to the number of available adsorption sites and our results shows that this number increases with the concentration of iron.

As seen in Fig. 4(c), the sensitivity of the $x=0.15$ sample to ozone at 250 °C is higher than that of the $x=0.10$ sample and decreases significantly when the work temperature increases to 310 °C. A decrease in the work temperature to 190 °C causes an increase in resistivity of one order of magnitude and increases considerably the recovery time compared with the same sample measured at 250 °C. The sensor response, $S=R_0/R$, with $R < R_0$, was obtained by taking the ratio of the resistances in dry air and in ozone gas. For comparison, the values of R_0 and R were measured from the experimental data collected at 250 °C for different amounts of ozone. For a determined amount of gas and temperature, the R_0 value was measured when the sample resistance achieved its steady value whereas the R value was measured after 2 min ($x=0.075$ and $x=0.15$) and 3 min ($x=0.10$). Table 1 compares the sensor responses obtained with our samples with those of In_2O_3 - and WO_3 -based ozone sensors. The sensitivity to ozone of our STF $x=0.075$ sample is like that of WO_3 but significantly lower than that of In_2O_3 . The response and recovery times of $x=0.075$ sample are comparable to those of In_2O_3 -based ozone sensor which presents a response time of 1 min and a recovery time of about 10 min [37]. The response to ozone of the STF $x=0.15$ sample at 220 °C and 190 °C are relatively higher but their recovery time is longer when compared to $x=0.075$ sample.

The process of interaction and detection of ozone gas with oxide materials has been described by different works in the literature [38]. The corresponding chemical reactions between a triatomic molecule O_3 and one free adsorption site, A, can be described by the following reaction [38]:



Ozone interacts directly with the metal oxide surface. In this case (strong chemisorptions), an electron of the conduction band is transferred from the semiconductor to the adsorbed species decreasing thus the sensor resistance.

According to the XRD and AFM data, the increasing of iron content does not notably affect the structure and the morphological properties of the STF thin films. The sensor response cannot be also attributed directly to the increase of iron because $x=0.10$ sample presents a lower response of $x=0.075$ sample. In this way, further study still needs to be done to understand the detailed gas-sensing mechanism of the STF samples.

4. Conclusions

Perovskite nanostructured $\text{SrTi}_{1-x}\text{Fe}_x\text{O}_3$ (STF) thin films containing 0.075, 0.10 and 0.15 mol% of iron were prepared by electron beam evaporation using as targets samples obtained by the polymeric precursor method. STF thin films are polycrystalline after annealing and present a distribution of iron that seems to be homogeneous. The STF thin-film sensor response to ozone was verified as a function of ozone content and working temperature. We found that the $x=0.075$ sample operating at 250 °C exhibits the best ozone sensitivity, response and recovery times. Further work is needed in order to optimize the sensor response and recovery time, as well as to avoid the variation of the baseline between the gas sensing cycles and to find the relationship between iron content, morphology and sensor response.

Acknowledgments

This work was sponsored by the program CAPES-COFECUB. We also are grateful for the financial support of the Brazilian Council for Scientific and Technological Development (CNPq) and the State of São Paulo Research Foundation (FAPESP).

References

- [1] C.Y. Wang, R.W. Becker, T. Passow, W. Pletschen, K. Kohler, V. Cimalla, O. Ambacher, Photon stimulated sensor based on indium oxide nanoparticles I: wide-concentration-range ozone monitoring in air, *Sensors and Actuators B* 152 (2011) 235–240.
- [2] G. Korotcenkov, B.K. Cho, Ozone measuring: what can limit application of SnO₂-based conductometric gas sensors? *Sensors and Actuators B* 161 (2012) 28–44.
- [3] M.Z. Atashbar, B. Gong, H.T. Sun, W. Wlodarski, R. Lamb, Investigation on ozone-sensitive In₂O₃ thin films, *Thin Solid Films* 354 (1999) 222–226.
- [4] M. Bender, N. Katsarakis, E. Gagaoudakis, E. Hourdakakis, E. Douloufakis, V. Cimalla, G. Kiriakidis, Dependence of the photoreduction and oxidation behavior of indium oxide films on substrate temperature and film thickness, *Journal of Applied Physics* 90 (2001) 5382–5387.
- [5] M. Epifani, E. Comini, J. Arbiol, E. Pellicer, P. Siciliano, G. Faglia, J.R. Morante, Nanocrystals as very active interfaces: ultrasensitive room-temperature ozone sensors with In₂O₃ nanocrystals prepared by a low-temperature sol-gel process in a coordinating environment, *Journal of Physical Chemistry C* 111 (2007) 13967–13971.
- [6] C.Y. Wang, V. Cimalla, T. Kups, C.C. Rohlig, H. Romanus, V. Lebedev, J. Pezoldt, T. Stauden, O. Ambacher, Photoreduction and oxidation behavior of In₂O₃ nanoparticles by metal organic chemical vapor deposition, *Journal of Applied Physics* 102 (2007) 044310.
- [7] C.Y. Wang, V. Cimalla, T. Kups, C.C. Rohlig, T. Stauden, O. Ambacher, M. Kunzer, T. Passow, W. Schirmacher, W. Pletschen, K. Kohler, J. Wagner, Integration of In₂O₃ nanoparticle based ozone sensors with GaInN/GaN light emitting diodes, *Applied Physics Letters* 91 (2007) 103509.
- [8] T. Takada, K. Suzuki, M. Nakane, Highly sensitive ozone sensor, *Sensors and Actuators B* 13 (1993) 404–407.
- [9] A. Gurlo, N. Barsan, M. Ivanovskaya, U. Weimar, W. Gopel, In₂O₃ and MoO₃-In₂O₃ thin film semiconductor sensors: interaction with NO₂ and O₃, *Sensors and Actuators B* 47 (1998) 92–99.
- [10] C. Baratto, M. Ferroni, G. Faglia, G. Sberveglieri, Iron-doped indium oxide by modified RGTG deposition for ozone sensing, *Sensors and Actuators B* 118 (2006) 221–225.
- [11] M. Suchea, N. Katsarakis, S. Christoulakis, S. Nikolopoulou, G. Kiriakidis, Low temperature indium oxide gas sensors, *Sensors and Actuators B* 118 (2006) 135–141.
- [12] G. Korotcenkov, A. Cerneavski, V. Brinzari, A. Vasiliev, M. Ivanov, A. Cornet, J. Morante, A. Cabot, J. Arbiol, In₂O₃ films deposited by spray pyrolysis as a material for ozone gas sensors, *Sensors and Actuators B* 99 (2/3) (2004) 297–303.
- [13] G. Korotcenkov, V. Brinzari, A. Cerneavski, M. Ivanov, V. Golovanov, A. Cornet, J. Morante, A. Cabot, J. Arbiol, The influence of film structure on In₂O₃ gas response, *Thin Solid Films* 460 (1/2) (2004) 315–323.
- [14] K. Aguir, C. Lemire, D.B.B. Lollman, Electrical properties of reactively sputtered WO₃ thin films as ozone gas sensor, *Sensors and Actuators B* 84 (2002) 1–5.
- [15] M. Bendahan, R. Boulmani, J.L. Seguin, K. Aguir, Characterization of ozone sensors based on WO₃ reactively sputtered films: influence O₂ concentration in the sputtering gas and working temperature, *Sensors and Actuators B* 100 (2004) 320–324.
- [16] R. Boulmani, M. Bendahan, C. Lambert-Mauriat, M. Gillet, K. Aguir, Correlation between rf-sputtering parameters and WO₃ sensor response towards ozone, *Sensors and Actuators B* 125 (2007) 622–627.
- [17] W. Belkacem, A. Labidi, J. Guerin, N. Mliki, K. Aguir, Cobalt nanograins effect on the ozone detection by WO₃ sensors, *Sensors and Actuators B* 132 (2008) 196–201.
- [18] G. Korotcenkov, B.K. Cho, Thin film SnO₂-based gas sensors: film thickness influence, *Sensors and Actuators B* 142 (2009) 321–330.
- [19] F. Berger, B. Ghaddab, J.B. Sanchez, C. Mavon, Development of an ozone high sensitive sensor working at ambient temperature, *Sensors and Their Applications XVI – Journal of Physics: Conference Series* 307 (2011) 012054.
- [20] S. Zhou, X.D. Fang, Z.H. Deng, D. Li, W.W. Dong, R.H. Tao, G. Meng, T. Wang, Room temperature ozone sensing properties of p-type CuCrO₂ nanocrystals, *Sensors and Actuators B* 143 (2009) 119–123.
- [21] J.H. Yu, J.H. Kim, T.S. Jeong, C.J. Youn, K.J. Hong, Formation and characterization of co-sputtered CdZnO layers for ozone sensing, *Journal of the Korean Physical Society* 59 (2) (2011) 289–293.
- [22] P. Meuffels, Propane gas sensing with high-density SrTi_{0.6}Fe_{0.40}(3-delta) ceramics evaluated by thermogravimetric analysis, *Journal European Ceramic Society* 27 (2007) 285–290.
- [23] A. Rothschild, H.L. Tuller, Gas sensors: new materials and processing approaches, *Journal of Electroceramics* 17 (2006) 1005–1012.
- [24] R. Moos, W. Menesklou, H.J. Schreiner, K.H. Härdtl, Materials for temperature independent resistive oxygen sensors for combustion exhaust gas control, *Sensors and Actuators B* 67 (2000) 178–183.
- [25] D.E. Willians, Semiconducting oxides as gas-sensitive resistors, *Sensors and Actuators B* 57 (1999) 1–16.
- [26] T. Hara, T. Ishiguro, N. Wakiya, K. Shinozaki, Oxygen sensitivity of perovskite-type dielectric thin films, *Materials Science and Engineering B: Advanced Functional Solid-State Materials* 161 (2009) 142–145.
- [27] A. Rothschild, S.J. Litzelman, H.L. Tuller, W. Menesklou, T. Schneider, E. Ivers-Tiffée, Temperature-independent resistive oxygen sensors based on SrTi_{(1-x)Fe(x)O(3-delta)} solid solutions, *Sensors and Actuators B* 108 (2005) 223–230.
- [28] K. Sahner, R. Moos, M. Matam, J.J. Tunney, M. Post, Hydrocarbon sensing with thick and thin film p-type conducting perovskite materials, *Sensors and Actuators B* 108 (2005) 102–112.
- [29] M. Vrčar, A. Kuzmin, R. Merkle, J. Purans, E.A. Kotomin, J. Maier, O. Mathon, Jahn-Teller distortion around Fe(4+) in Sr(Fe(x)Ti(1-x))O(3-delta) from X-ray absorption spectroscopy, X-ray diffraction, and vibrational spectroscopy, *Physical Review B* 76 (2007) 174107.
- [30] A. Rothschild, W. Menesklou, H.L. Tuller, E. Ivers-Tiffée, Electronic structure, defect chemistry, and transport properties of SrTi_{1-x}Fe_xO_{3-y} solid solutions, *Chemistry of Materials* 18 (2006) 3651–3659.
- [31] E. Mashkina, A. Magerl, J. Ollivier, M. Göbbels, F. Seifert, Oxygen mobility in the perovskite SrTi_{1-x}Fe_xO_{3-δ} (x=0.8), *Physical Review B* 74 (2006) 214106.
- [32] G. Neri, A. Bonavita, G. Micali, G. Rizzo, R. Licheri, R. Orru, G. Cao, Resistive lambda-sensors based on ball milled Fe-doped SrTiO₃ nanopowders obtained by self-propagating high-temperature synthesis (SHS), *Sensors and Actuators B* 126 (2007) 258–265.
- [33] K. Sahner, R. Moos, Modeling of hydrocarbon sensors based on p-type semiconducting perovskites, *Physical Chemistry Chemical Physics* 9 (2007) 635–642.
- [34] W. Menesklou, H.J. Schreiner, K.H. Härdtl, E. Ivers-Tiffée, High temperature oxygen sensors based on doped SrTiO₃, *Sensors and Actuators B* 59 (1999) 184–189.
- [35] L.F. da Silva, M.I.B. Bernardi, L.J.Q. Maia, E.G.J.M. Frigo, V.R. Mastelaro, Synthesis and thermal decomposition of SrTi_{1-x}Fe_xO₃ powders obtained by the polymeric precursor method, *Journal of Thermal Analysis and Calorimetry* 97 (2009) 173–177.
- [36] L.F. da Silva, L.J.Q. Maia, M.I.B. Bernardi, J.A. Andres, V.R. Mastelaro, An improved method for preparation of SrTiO₃ nanoparticles, *Materials Chemistry and Physics* 125 (2011) 168–173.
- [37] M. Epifani, G. Leo, M. Lomascolo, L. Vasanelli, L. Manna, Sol-gel synthesis of hybrid organic-inorganic monoliths doped with colloidal CdSe/ZnS core-shell nanocrystals, *Journal of Sol-Gel Science and Technology* 26 (1–3) (2003) 441–446.
- [38] J. Guerin, A. Bendahan, K. Aguir, A dynamic response model for the WO₃-based ozone sensors, *Sensors and Actuators B* 128 (2008) 462–467.

Biographies

Valmor Roberto Mastelaro is currently associated professor at the Institute of Physics of São Carlos, University of Sao Paulo, Brazil. He received his Doctor in science from Université Paris XI (France) in 1992. He research interests mostly deal with structural characterization of inorganic materials by X-ray diffraction spectroscopy (XAS) and electrical properties of perovskite oxide based ceramic materials. He is the (co) author of over 110 papers in international peer-reviewed journals.

Sérgio Carlos Zilio received his Ph.D. in physics from the University of São Paulo, at São Carlos, in 1983. He is currently full professor at the Institute of Physics of São Carlos, University of Sao Paulo. His research interests include nonlinear optics and optical instrumentation.

Luis Fernando Silva is a Ph.D. student in materials science from Physics Institute of São Carlos, University of São Paulo, São Carlos, Brazil since 2009 with a fellowship from Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq). The aim of his thesis is the synthesis and characterization of SrTi_{1-x}Fe_xO₃ nanocrystalline samples obtained by the microwave assisted hydrothermal method.

Pedro I. Pellissari was a Master student in Physics from University of São Paulo, São Carlos, Brazil, with a fellowship from Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq). The aim of his master's dissertation was the synthesis and characterization of SrTi_{1-x}Fe_xO₃ thin films prepared by electron beam evaporation technique.

Maria Inês Basso Bernardi received her Ph.D. degree in materials science and engineering from Federal University of São Carlos (2001). She is currently a researcher of the São Carlos Institute of Physics, University of São Paulo, Brazil. Her main areas of interest are synthesis and structural, morphological, optical, catalytic and sensor characterization of nanostructure materials. She is the (co)author of over 55 papers in international peer-reviewed journals.

Jacques Guérin received his engineering diploma in electronics and radio communication at the Institut National Polytechnique de Grenoble (INPG) and his Ph.D. from the Aix-Marseille University with a thesis on spatial silicon solar cells for observation satellites. After various research and engineering developments (thermionic conversion, electronic power devices, etc.), he joined the Sensors Group of the Institute of Materials & Microelectronics of Provence (IM2NP-CNRS) Marseille (France) in 2002. Its principal research interests are now directed toward gas sensors and selectivity

enhancement strategies, conduction and adsorption mechanisms and modeling of sensor responses.

Khalifa Aguir is a professor at Aix Marseille University (France). He was awarded his Doctorat d'Etat ès Sciences degree from Paul Sabatier University, Toulouse (France) in 1987. He is currently the head of Microsensors Group at the Institute of Materials

Microelectronic Nanosciences of Provence (IM2NP-CNRS) at Aix-Marseille University, Marseille (France). His principal research interests are now directed toward metal-oxide (WO_3 , SrTiO_3 , CuO , CeO_2) and organic thin films for gas sensors, flexible gas sensors, microsystems, selectivity enhancement strategies including surface modification of sensors, signal treatment, adsorption-desorption noise spectroscopy, modeling of sensor responses analysis and low noise amplifier Design.