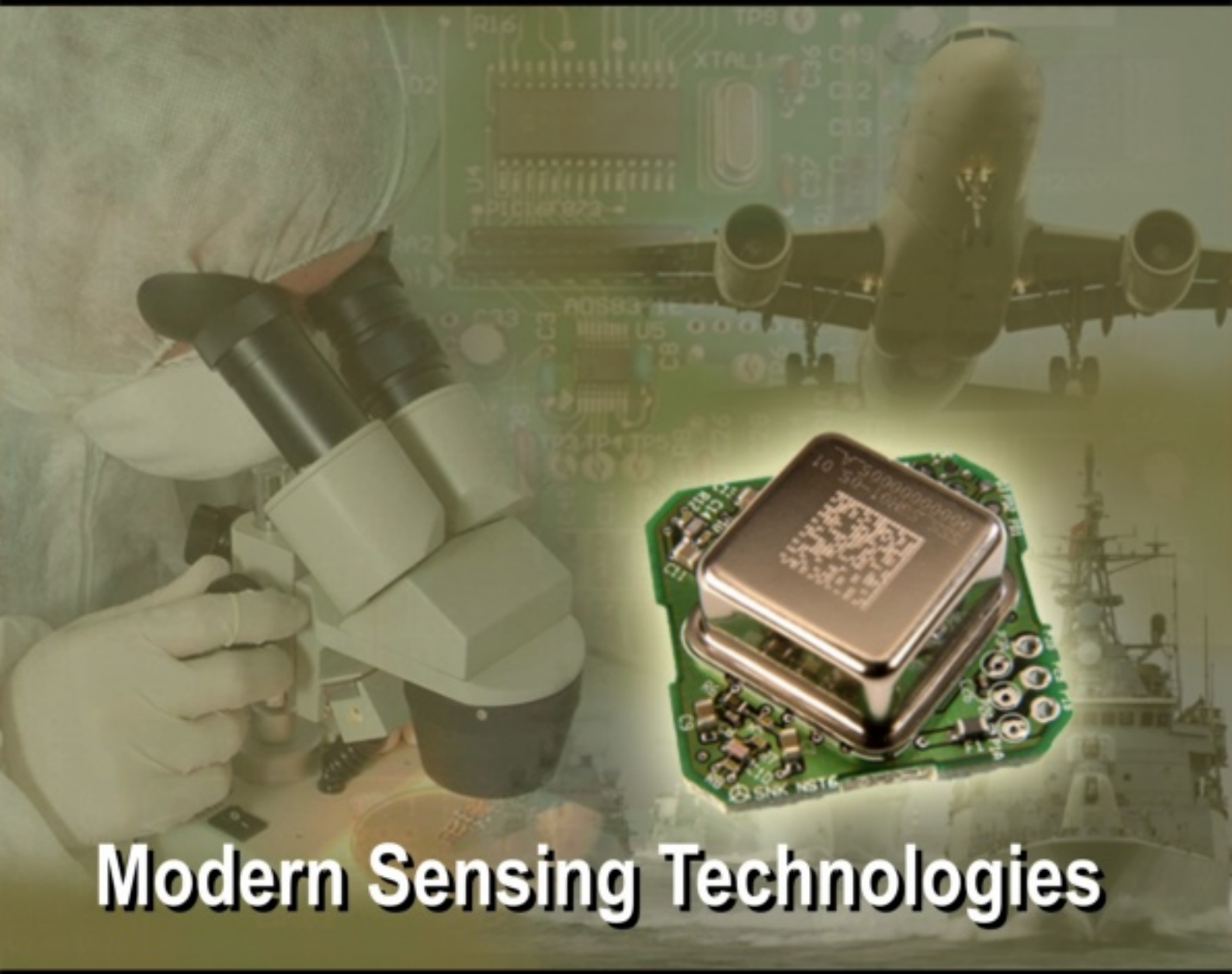
ISSN 1726-5749

SENSORS & TRANSDUCERS

vol. 90 Special 4/08



Modern Sensing Technologies

International Frequency Sensor Association Publishing

IFSA

Sensors & Transducers

Special Issue
April 2008

www.sensorsportal.com

ISSN 1726-5479

Sensors & Transducers Journal (ISSN 1726-5479) is a peer review international journal published monthly online by International Frequency Sensor Association (IFSA). Available in electronic and CD-ROM.

Sensors & Transducers Journal

Contents

Volume 90
Special Issue
April 2008

www.sensorsportal.com

ISSN 1726-5479

Special Issue on Modern Sensing Technologies

Sensors Signal Processing

Gas Sensors

Image Sensors

Miscellaneous

Authors are encouraged to submit article in MS Word (doc) and Acrobat (pdf) formats by e-mail: editor@sensorsportal.com
Please visit journal's webpage with preparation instructions: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm

Sensors & Transducers Journal, Vol. 90, Special Issue, April 2008, pp. 160-173

www.sensorsportal.com

Sensors & Transducers

ISSN 1726-5479

http://www.sensorsportal.com

Gas Sensing Performance of Pure and Modified BST Thick Film Resistor

[*1]G. H. JAIN, [2]V. B. GAIKWAD, [1]D. D. KAJALE, [2]R. M. CHAUDHARI, [2]R. L. PATIL, [3]N. K. PAWAR, [1]M. K. DEORE, [2]S. D. SHINDE and [4]L. A. PATIL

[1]Department of Physics, Arts, Commerce and Science College,
Nandgaon, India 423 106,
[2]Department of Chemistry, K. T. H. M. College,
Nashik, India 422 002,
[3]Department of Physics, K.A.A.N.S. Arts, Commerce and Science College, Satana, India,
[4]Material Science Laboratory, Pratap College,
Amalner, India 425 401
*E-mail: gotanjain@rediffmail.com

Received: 15 October 2007 /Accepted: 20 February 2008 /Published: 15 April 2008

Abstract: Barium Strontium Titanate (BST-($Ba_{0.87}Sr_{0.13}$)TiO_3) ceramic powder was prepared by mechanochemical process. The thick films of different thicknesses of BST were prepared by screen-printing technique and gas-sensing performance of these films was tested for various gases. The films showed highest response and selectivity to ammonia gas. The pure BST film was surface modified by surfactant CrO_3 by using dipping technique. The surface modified film suppresses the response to ammonia and enhances to H_2S gas. The surface modification of films changes the adsorption-desorption relationship with the target gas and shifts its selectivity. The gas response, selectivity, response and recovery time of the pure and modified films were measured and presented.

Keywords: Barium Strontium Titanate, Thick films, Ammonia gas sensor, H_2S gas sensor, Selectivity

1. Introduction

The sensors are required basically for measurement of physical quantities and for use of controlling some systems. Presently, the atmospheric pollution has become a global issue. Gases from auto and industrial exhausts are polluting the environment. In order to detect, measure and control these gases,

one should know the amount and type of gases present in the ambient. Thus, the need to monitor and control these gases has led to the research and development of a wide variety of sensors using different materials and technologies. Gas sensitive resistors based on semiconducting oxides are simple and robust devices which owe their response to changes in charge-carrier concentration within a depletion layer at the solid-gas interface, in turn caused by a change in the surface density of electron trap states [1, 2]. They raise interesting questions of surface chemistry: the effects are considered due either to change in the surface coverage of the adsorbed oxygen species, caused by a reaction with the gas, or to adsorption of a gas species generating a new surface trap state.

Detection of ammonia (NH_3) is required in many applications including leak-detection in air conditioning systems [3], sensing of trace amounts in air for environmental analysis [4], breath analysis for medical diagnoses [5], animal housing and more. Generally, because it is toxic, it is required to be able to sense low levels of NH_3, but it should also be sensitive to much higher levels. NH_3 gas is very corrosive, often causing existing NH_3 sensors to suffer from drift, which have short life times. The ammonia sensors that have been manufactured in the largest quantities are mostly based on SnO_2 sensors [6-11]. Some of the well-known materials for ammonia sensors are pure ZnO [12, 13], SnO_2 [14], TiO_2 [15], Cr_2O_3-doped TiO_2 [16], etc.

A different approach to make selective metal-oxide gas sensor is by using metals or additives that enhance the chemisorptions of specific gases. WO_3 based sensing material is demonstrated to respond to NH_3 [17-18]. Very low detection limits of 1 ppm for ammonia sensing have been reported using a WO_3 ammonia sensor with Au and MoO_3 additives. This sensor is operated at an elevated temperature of more than 400^oC [18]. Most sensors have much higher detection limits. Normal detection of these sensors ranges from 1 to 1000 ppm [18, 19]. Another type of widely used ammonia sensor, employing electrolyte solutions with diaphragm electrodes, has major limitations due to the cost of fabrication and its relatively poor sensitivity and selectivity. Similarly, Pd gate metal oxide semiconductor device is also sensitive to ammonia but it does not offer sufficient selectivity, because ammonia is indirectly detected by sensing the hydrogen after decomposition [20].

The pervoskite oxides (ABO_3) were used as gas sensor materials for their stability in thermal and chemical atmospheres. So, over a last decade, the pervoskite oxide ceramic such as $BaTiO_3$ [21-24] and (Ba,Sr)TiO_3 [25-29] have created and promoted interest in chemical sensors. Modifications in microstructure, processing parameters and also concentration of acceptor/donor dopant can vary the temperature coefficient of the resistance and conductivity of ABO_3 oxides. Sensors based on ABO_3–type complex oxide material, of rare earth elements have an outstanding merit of its high sensitive and selective characteristics. These characteristics can be controlled by selecting suitable A and B atoms or chemically doping A′ and B′ elements equivalent respectively to A and B into ABO_3 to obtain $A_xA'_{1-x}B_yB'_{1-y}O_3$ compound [30, 31]. Jain and Patil [32] have reported the sensing behaviour of pure and modified $(Ba_{0.67}Sr_{0.33})TiO_3$, and showed that unmodified and modified $(Ba_{0.67}Sr_{0.33})TiO_3$ are sensitive to H_2S gas.

The present work is to explain the gas sensing performance of $(Ba_{0.87}Sr_{0.13})TiO_3$ (BST) and modified $(Ba_{0.87}Sr_{0.13})TiO_3$ thick film resistors. In the present study, it has been observed that response to NH_3 gas increases with increase in $(Ba_{0.87}Sr_{0.13})TiO_3$ film thickness up to certain limit, beyond that the response decreases on further increase in thickness. However, Roy et al [29] reported that the NH_3 gas response goes on increasing with film thickness. The NH_3 gas response varied depending upon the thicknesses, micro-structural variations, operating temperature and the concentration of gas. $(Ba_{0.87}Sr_{0.13})TiO_3$ thick films were surface modified using chromium trioxide (CrO_3) solution by dipping technique. The surface modification shifts the response of $(Ba_{0.87}Sr_{0.13})TiO_3$ thick film from NH_3 to H_2S gas.

2. Experimental

2.1. Powder Preparation

Barium Strontium Titanate (BST-($Ba_{0.87}Sr_{0.13}$)TiO_3) ceramic powder was prepared by mechanochemical process, explained elsewhere [33]. The XRD spectrum of as prepared powder confirmed the sub microcrystalline pervoskite phase. The composition ratios (Ba/Sr) of the as prepared powder were confirmed using the microarea EDS analysis.

2.2. Preparation of Thick Films

The thixotropic paste was formulated by mixing the fine powder of BST with the solution of ethyl cellulose (a temporary binder) in a mixture of organic solvents such as butyl cellulose, butyl carbitol acetate and terpineol etc. The ratio of inorganic part to organic part was kept at 75:25 in formulating the paste. This paste was screen printed [24] on glass substrate in the desired pattern. The films were fired at 550^{o}C for 30min.

2.3. Variation of Thickness

The thickness of the films was measured by using the Taylor–Hobson (Talystep, UK) system. The thicknesses of the films were observed in the range from 65–70 mm. The reproducibility in thickness of the films was possible by maintaining proper rheology and thixotropy of the paste. Films of various thicknesses were prepared by controlling the number of impressions of squeeze strokes. Different films of thicknesses: 1BST(17μm), 2BST(33μm), 3BST(48μm) and 4BST(63μm), were printed. The reproducibility in the thickness of the films was possible by maintaining proper rheology and thixotropy of the paste.

2.4. Surface Modification of Films

The surface modified 2BST thick films were obtained by dipping them in a 0.1M aqueous solution of chromium trioxide (CrO_3) for different intervals of dipping time: 5, 10, 20 and 30min. These films were dried at 80^{o}C, followed by firing at 550^{o}C for 30min. These surface modified films are termed as 'Cr_2O_3-modified' BST films.

2.5. Characterization

The structural properties of the powder were studied using a Rigaku model DMAX-2500 X-ray diffractometer (XRD) with Cu.Kα radiation, having λ = 1.5406 Å. The microstructure and chemical compositions of the films were analyzed using a scanning electron microscope (SEM, JEOL JED 6300) coupled with an energy dispersive spectrometer (EDS, JEOL JED2300LA). The thicknesses of the thick films were measured using a Taylor–Hobson (Talystep, UK) system. The sensing performance of the sensors was examined using a 'static gas sensing system' explained elsewhere [24].

3. Results and Discussion

3.1. Structural Analysis

Fig. 1 shows the X-ray diffractogram of screen-printed BST thick film fired at 550°C in air atmosphere.

XRD analysis revealed that the material is polycrystalline in nature with tetragonal pervoskite phase. The positions of the peaks matched well with the ASTM data book, card No. 34-11 and the average grain size determined from Scherer formula is estimated to be 264 nm.

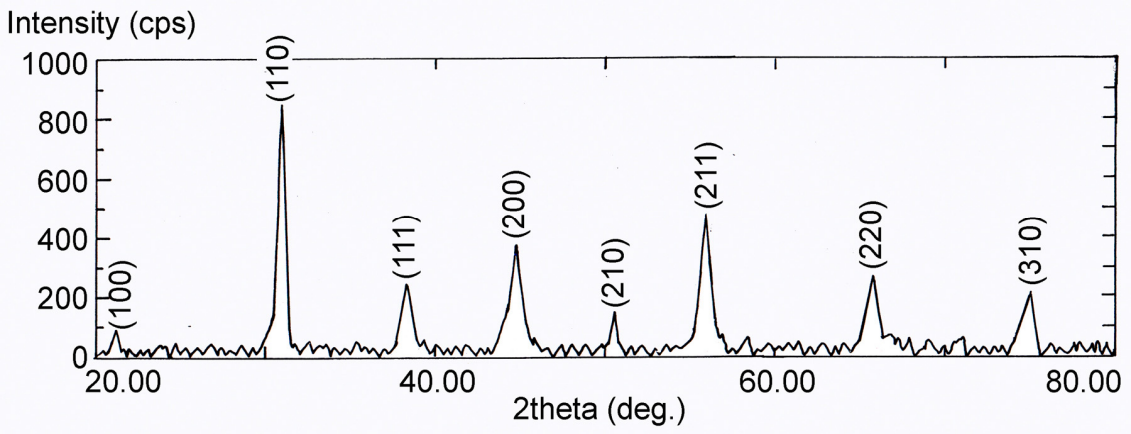


Fig. 1. X-ray diffractogram of the BST thick film.

3.1. Microstructural Analysis

Fig. 2(a) depicts the SEM image of unmodified 2BST (thickness: 33μm) thick film fired at 550°C. The film consists of a large number of grains leading to high porosity and large effective surface area available for the adsorption of oxygen species. Fig. 2(b) is the SEM image of the unmodified 4BST film having larger thickness (63μm), which is comparatively less porous and grains are agglomerated. Effective surface to volume ratio would be decreased and less number of oxygen ions would be adsorbed on film in Fig. 2(b) as compared to the film in Fig. 2(a).

Fig. 2(c) is the SEM image of a Cr_2O_3-modified 2BST (thickness: 33μm) film for the dipping time interval of 5min. The micrograph appears to consist of relatively small number of smaller particles distributed around the larger BST particles. The small particles may be of Cr_2O_3. Fig. 2(d) is the SEM image of a Cr_2O_3-modified 2BST (33μm) film for the dipping time interval of 20min.

3.2. Quantative Elemental Analysis of Unmodified and Modified Films

The quantitative elemental composition of surface modified films obtained by dipping technique were analyzed using energy dispersive spectrometers have been presented in Table 1.

Stoichiometrically (theoretically) expected wt% of cations (Ba+Sr+Ti) and anions (O) are 85.02 and 14.98, respectively. The wt% of constituent cations and anions in as prepared BST and Cr_2O_3-modified 2BST were not as per the stoichiometric proportion and all samples were observed to be oxygen deficient, leading to the semiconducting nature of BST. It is clear from Table 1 that the weight

percentage of Cr_2O_3 went on increasing with dipping time. The film with the dipping time of 20 min is observed to be more oxygen deficient (5.92wt.%). This oxygen deficiency would promote the adsorption of relatively larger amount of oxygen species favourable for higher gas response.

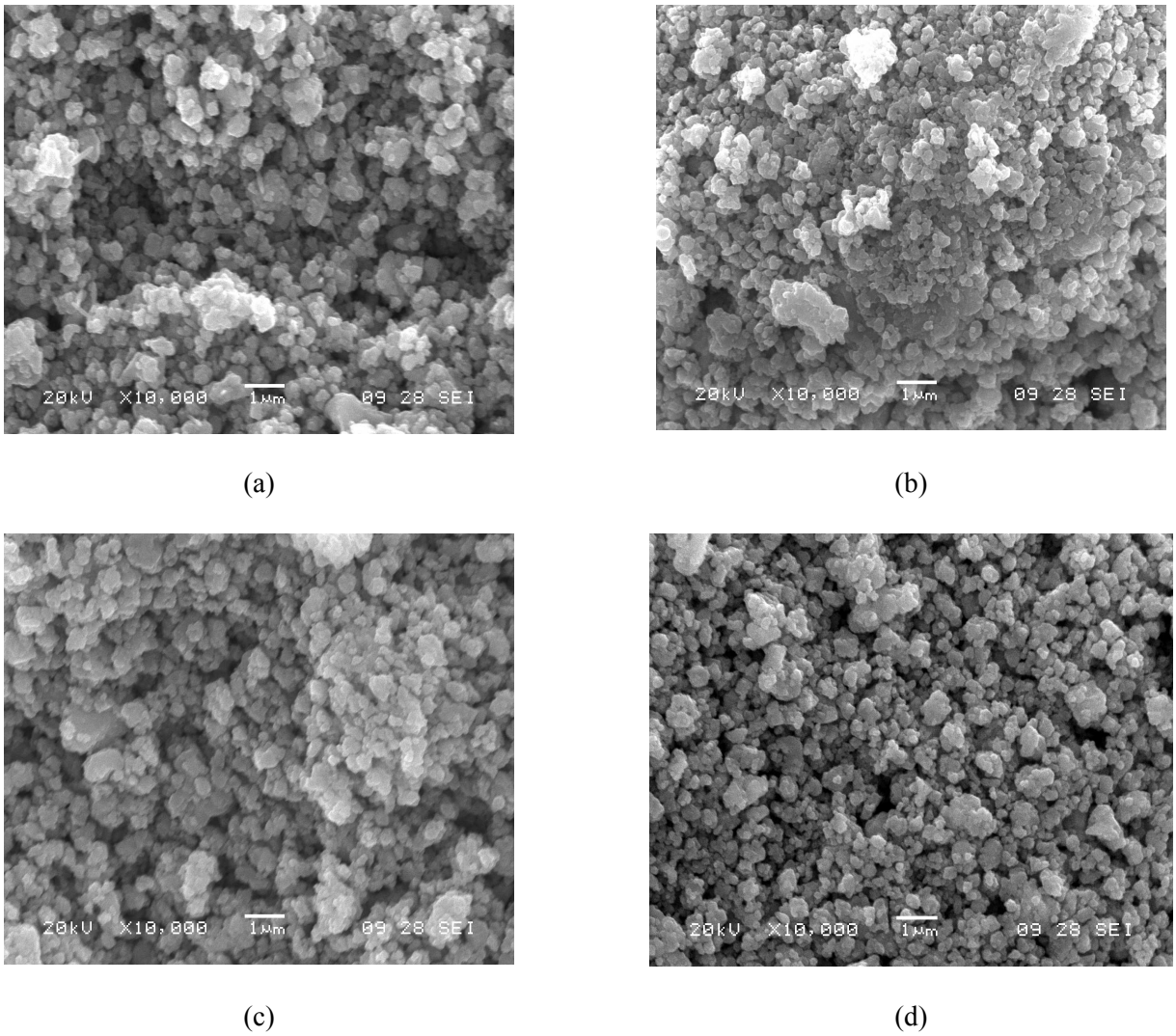


Fig. 2. SEM images of unmodified: (a) 2BST (33μm), (b) 4BST (63μm) and surface modified dipped for: (c) 5min and (d) 20 min 2BST (33μm) films.

Table 1. Quantitative elemental analysis.

Elements (wt%)	**Dipping Time (min)**				
	0	**5**	**10**	**20**	**30**
(Ba+Sr+Ti)	93.16	93.28	92.84	93.24	92.55
Cr	00	0.51	0.80	0.84	0.93
O	6.84	6.21	6.36	5.92	6.52
BST	100	99.2546	98.8307	98.7723	98.6407
Cr_2O_3	00	0.7454	1.1693	1.2277	1.3593

3.2. Thermal Analysis

Fig. 3 shows the thermogravimetric profile of pure and Cr_2O_3-modified 2BST films. Table 2 lists loss or gain in weight percentage of pure and Cr_2O_3-modified 2BST films in the different ranges of temperature observed from TGA. Comparatively a less weight loss and a more gain in the Cr_2O_3-modified 2BST sample can be attributed to the adsorbed oxygen content.

The film with the content of Cr_2O_3 (1.2277wt%) has been observed to contain the smallest amount of oxygen (5.92wt%, Table 1), which could be attributed to the largest deficiency of oxygen in the film. It is, therefore, quite possible that the material would adsorb the largest possible amount of oxygen, showing a relatively less weight loss. The Cr_2O_3 on the surface of modified sample would form misfits regions between the grains of BST and could act as an efficient catalyst for oxygenation.

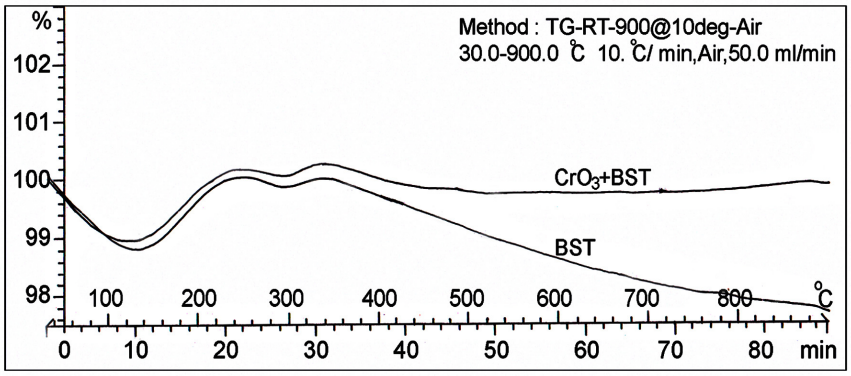


Fig. 3. TGA of pure and Cr_2O_3-modified 2BST films.

Table 2. Thermal analysis.

Temp. (^oC)	Pure 2BST		Temp. (^oC)	Cr_2O_3-modified 2BST	
	Loss (wt%)	Gain (wt%)		Loss (wt%)	Gain (wt%)
30-25	1.20	--	30-125	1.0	--
125-245	--	1.20	125-245	--	1.2
245-290	0.20	--	245-290	0.2	--
290-340	--	0.20	290-340	--	0.4
340-900	2.25	--	340-900	0.6	--

4. Gas Sensing Performance of Unmodified BST films

4.1. Unmodified BST Films

4.1.1. Gas Response with Operating Temperature

Gas response or sensitivity of a sensor is defined as the ratio of the conductance change upon exposure to a test gas to the conductance in air.

Fig. 4 shows the variation in NH_3 gas (300 ppm) response with operating temperatures (for films of various thicknesses). It is noted from the graph that the response goes on increasing with the increasing temperature, and attains a maximum at 300^{o}C, and decreases with further increase in operating

temperature for all thicknesses and film thickness of 33 μm is found to be most sensitive for sensing NH_3 gas.

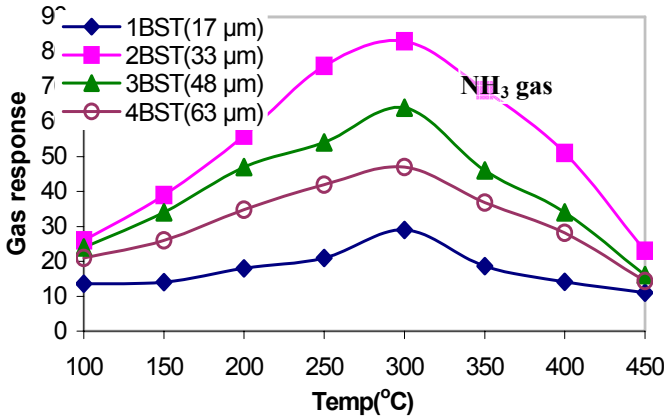


Fig. 4. Variation of NH_3 gas response with operating temperature for 300 ppm.

The variation in gas response with film thickness, and the sudden change in response at a particular thickness may be due to optimum porosity. The porosity appears to increase with increasing film thickness. Beyond a certain limit of thickness, the porosity may decrease due to densely populated particles, which could easily agglomerate. The increased porosity could promote the in-pore adsorption of oxygen, which could then improve the adsorption-desorption of the target gas.

4.1.2. Response and Recovery with Gas Concentrations

The time taken for the sensor to attain 90% of the maximum change in resistance upon exposure to the gas is the response time. The time taken by the sensor to get back 90% to the original resistance is the recovery time [34].

Fig. 5 shows the response and recovery profiles of the most sensitive unmodified 2BST film to ammonia gas at 300°C, and it is observed that the response and recovery time increase with gas concentration.

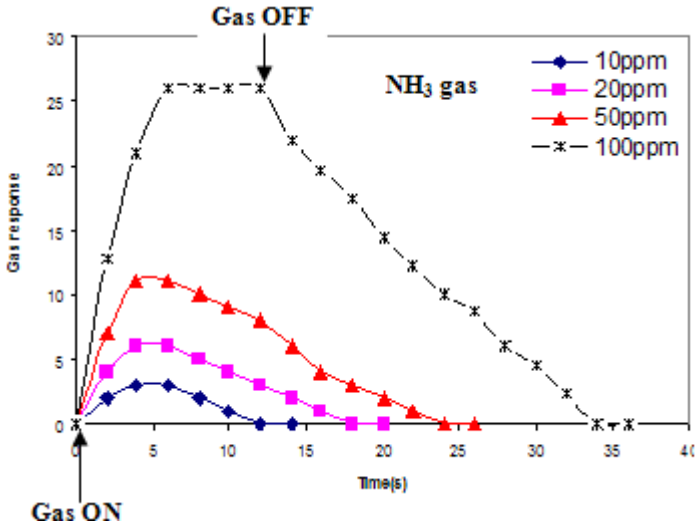


Fig. 5. Response speed of the (2BST) film at different NH_3 gas concentrations.

Table 4 shows the values of response and recovery times of different gas concentrations. It is revealed that for lower gas concentration the response and recovery times have been observed to be shorter, and become longer as gas concentration increases. The smaller the gas concentration the faster would be the oxidation of NH_3 gas and hence quick response and immediate recovery of the sensor are noted.

Table 4. Response and recovery times with gas concentrations.

Gas concentration (ppm)	Response Time (s)	Recovery Time (s)
10	3	10
20	4	16
50	5	20
100	6	32

4.2. Cr_2O_3-modified BST Films

4.2.1. Gas Response with Operating Temperature

Fig. 6 shows the variation of gas response of unmodified (pure) and Cr_2O_3-surface modified 2BST films to H_2S gas (300 ppm) with operating temperatures. The unmodified 2BST film showed weak response (S=26) to H_2S gas at 350°C, while the Cr_2O_3-modified BST films showed higher response (S=73) at 350°C. The surface modification would have enhanced the response to H_2S gas. The H_2S gas response of Cr_2O_3-modified 2BST goes on increasing with dipping time attains maximum (20 min) and, decreases on further increase in dipping time interval as indicated in the graph.

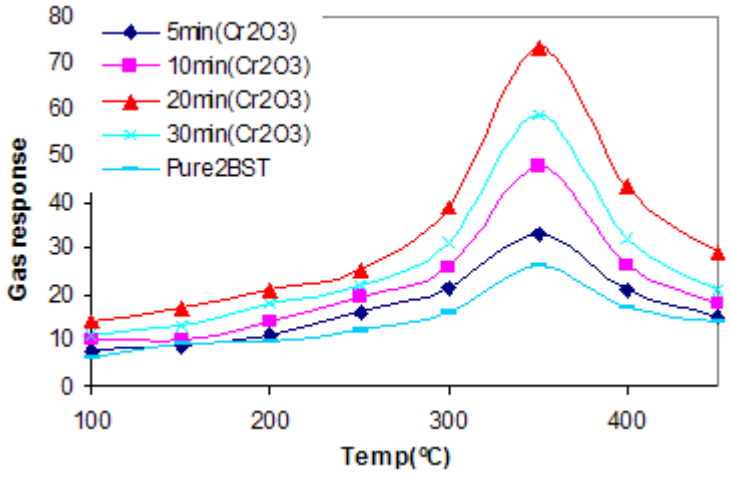


Fig. 6. H_2S gas response of pure and modified 2BST films with temperature.

4.2.2. Gas Response and Dipping Time

Fig. 7 shows the variation of NH_3 and H_2S gas response of the Cr_2O_3-modified 2BST films operated at 350°C and treated for the different intervals of time for modification. It is clear from figure that the response to NH_3 gas goes on decreasing, and response to H_2S gas goes on increasing with the increase of dipping time interval, NH_3 response reaches to maximum at 20 min then decreases with further increase in dipping time. Unmodified sample is more sensitive to NH_3 while Cr_2O_3-modified sample is more sensitive to H_2S. The shifting of response of the modified film to H_2S gas could be attributed to

conversion of Cr_2O_3 into Cr_2S_3, which is conducting in nature. Surface modification would have altered the adsorbate-adsorbent interactions so as to obtain unusual selectivity and sensitivity effects to H_2S gas.

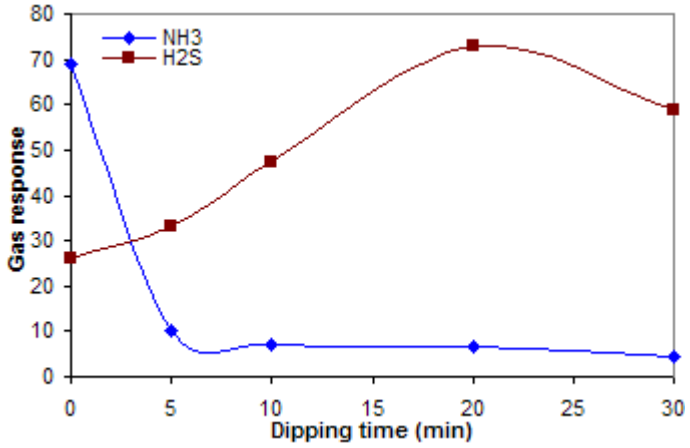


Fig. 7. Variation of NH_3 and H_2S gas response with dipping time.

4.2.3. Selectivity of Pure and Cr_2O_3-modified BST Films

The ability of a sensor to respond to a certain gas in the presence of other gases is known as selectivity.

Fig. 8 shows the histogram of selectivities of the pure and Cr_2O_3-modified 2BST film. It is clear from the histogram that the pure BST is more selective to NH_3 while Cr_2O_3-modified is more selective to H_2S gas. Cr_2O_3 misfits on the surface of the 2BST film would be responsible for the shifting from NH_3 to H_2S.

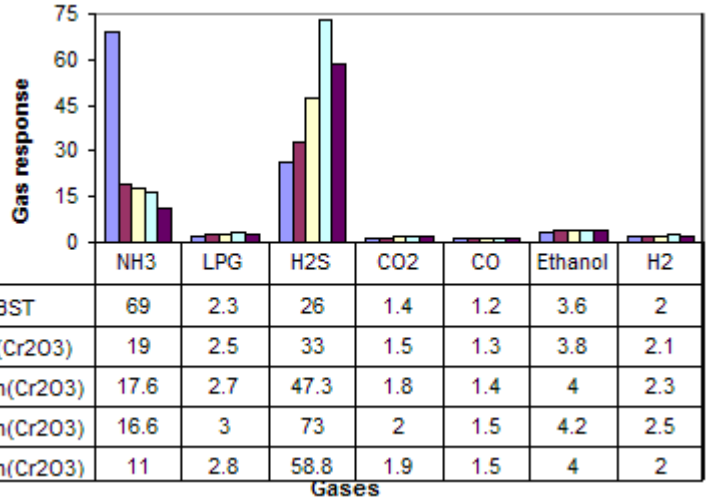


Fig. 8. Selectivity of the pure and Cr_2O_3-modified 2BST film.

4.2.4. Response and Recovery Time of Cr_2O_3-modified BST Film

The response and recovery profile of the most sensitive Cr_2O_3-modified 2BST film (20 min) is represented in Fig. 9.The response was quick (3 s) and the recovery time was 18s, at 350°C to H_2S gas for 30-ppm gas concentration.

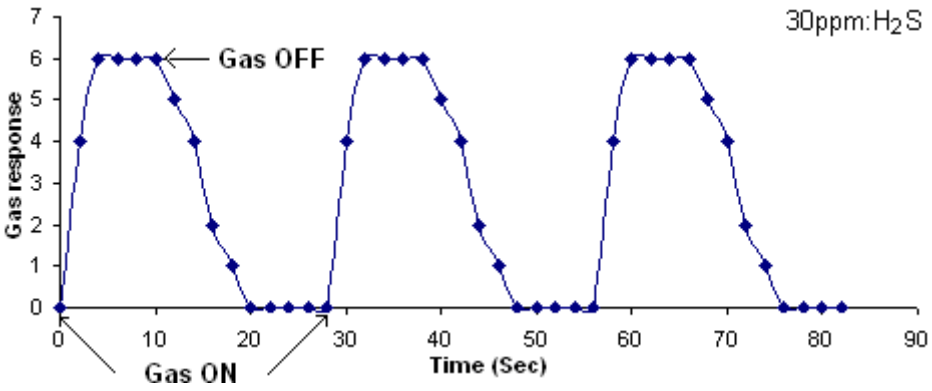


Fig. 9. Response and recovery of the Cr_2O_3-modified 2BST film.

The unmodified sample is more sensitive to NH_3 gas while Cr_2O_3-modified sample is more sensitive to H_2S gas. The shift in the response of the modified film to H_2S gas could be attributed to surface modification. Surface modification would alter the adsorbate-adsorbent interactions and allows unusual selectivity and high sensitivity to H_2S gas.

5. Discussion

5.1. BST as a NH_3 Sensor

The sensitivity of $(Ba_{0.87}Sr_{0.13})TiO_3$ to NH_3 could be attributed to the high oxygen deficiency and defect density and leads to increased oxygen adsorption. The larger the amount of oxygen adsorbed on the surface, the larger would be the oxidizing capability and faster would be the oxidation of NH_3 gas. The reactivity of NH_3 would have been very large as compared to H_2S gas with the surface under the same condition. Hydrite (NH_3) may have lower sensitivity than hydrogen exposed on particular metal oxide under the same condition [33]. The lower response to NH_3 may be related to firm binding state preventing fast decomposition and water formation. NH_3 could dissociate under certain favourable circumstances into $(NH_2)^-$ and H^+ irreversibly. The reaction of released hydrogen with adsorbed or lattice oxygen could increase the conductance leading to higher sensitivity to NH_3. NH_3 undergoes the following reaction on exposure to metal surface:

$$2NH_3 + O^-_{ads} + O_2 \rightarrow 2NO_2 + 3H_2O + 5e^- \quad (1)$$

The equation (1) represents the chemical reaction involved in the unmodified BST to sense NH_3 gas. NH_3 molecule has a lone pair of electrons. In comparison with other gases, NH_3 can readily donate the unpaired electrons to the metal ions of base material, which has unfilled orbits to form coordination complex. Furthermore, the coordinated NH_3 molecules easily react with oxygen adsorbates (O^-_{ads}) and the electrons bonded with adsorbed oxygen are returned back into the sensor, increasing the sensor conductivity.

The adsorbed oxygen on the surface of catalyst can be of several forms: O_2, O_2^- ,O^- and O^{2-}. Of these

species, O_2 is quite inactive because it is in very low concentration. If reducing agent is introduced, the O^- disappears very quickly relative to O_2^- indicating the O^- to be more active than O_2^-. The lattice oxygen, O^{2-}, can also be reactive with the incoming reducing agent.

5.2. Cr_2O_3-modified BST as a H_2S Gas Sensor

The chromium trioxide (CrO_3) on the surface of the BST film is not thermally stable above its melting point (197°C) losing oxygen to give Cr_2O_3 after a series of intermediate stages [35]. The H_2S gas is reducing in nature. It reduces Cr_2O_3 into Cr_2S_3 or CrS, which are metallic in nature and more conducting than Cr_2O_3. This can be represented as:

$$Cr_2O_3 + 3H_2S \rightarrow Cr_2S_3 + 3H_2O \quad (2)$$

or

$$Cr_2O_3 + 2H_2S \rightarrow 4CrO + 3SO_2 \quad (3)$$

$$CrO + H_2S \rightarrow CrS + H_2O \quad (4)$$

Due to the reduction of chromium oxide into sulphides, the film resistance would decrease suddenly and largely. This can be attributed to the high response of Cr_2O_3-modified BST film to H_2S.

Upon the subsequent exposure of sensor to air ambient at elevated temperatures, sulphides got oxidized and could be recovered back to oxides as:

$$2Cr_2S_3 + 9O_2 \rightarrow 2Cr_2O_3 + 6SO_2 \quad (5)$$

$$2CrS + 3O_2 \rightarrow 2CrO + 2SO_2 \quad (6)$$

The separate chemical identities (Cr_2O_3) on the surface can create artificial surface states in the midgap region, leading to unusual physical and chemical properties. For example, the adsorption energy can be higher for the misfit regions, and the discontinuity in the adsorption potential can give rise to unusual selectivity effects for Cr_2O_3-modified BST based semiconducting oxide sensors. There would be optimum number of Cr_2O_3 misfits (in case of film dipped for 20 min) distributed uniformly on the surface of the film. Cr_2O_3 misfits could act as catalyst for oxygenation leading to an increase in resistance by electron transfer from surface state to oxygen species. Due to the Cr_2O_3 misfits, the number of oxygen ions adsorbed on the surface would be largest. When H_2S gas comes in contact with Cr_2O_3-modified BST surface, it undergoes oxidation releasing electrons, decreasing resistance of the sensor and enhancing the response to H_2S. The reactivity of H_2S gas is expected to be high as compared to NH_3 under the same conditions section if it is necessary.

5.3. Effect of Dipping Time on Cr_2O_3 Dispersion

Fig. 10 illustrates the effect of dispersion of surface additive on the film conductivity. Uniform and optimum dispersion of an additive dominates the depletion of electrons from semiconductor. Oxygen adsorbing on additive (misfit) removes electrons from additive and additive in turn removes electrons from the nearby surface region of the semiconductor and could control the conductivity.

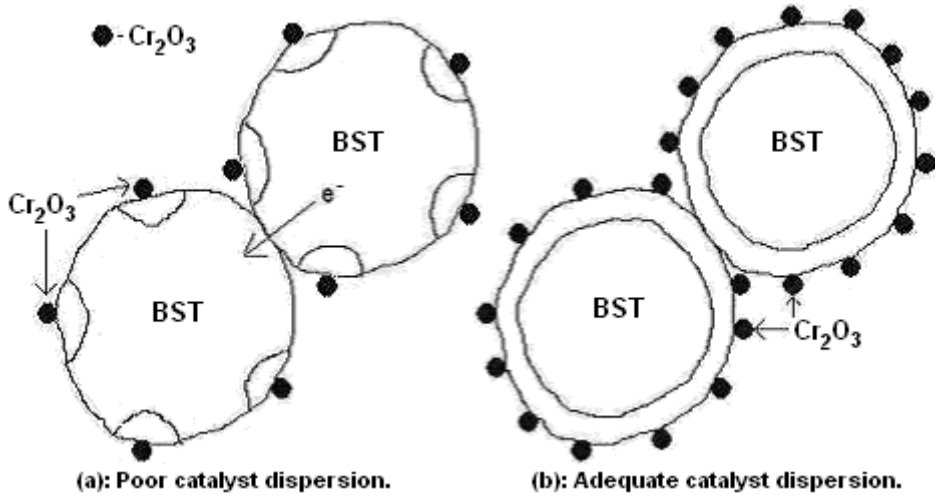


Fig. 10. Dispersion of additives.

For optimum dipping time (20 min), the number of Cr_2O_3 misfits would be optimum and would disperse uniformly covering the complete film surface (Fig. 10(a)). An adequate dispersion of Cr_2O_3 misfits (20 min) on film surface would produce depletion region on the grain surfaces and conductivity could be monitored systematically. The film conductivity would be very low in air and very high on exposure of H_2S gas (due to conversion of Cr_2O_3 into Cr_2S_3) and therefore the sensitivity would be largest.

For the dipping time smaller than the optimum, the number of Cr_2O_3 misfits would be smaller, their dispersion would be poor and the depletion regions would be discontinuous and there would be the paths to pass electrons from one grain to another (Fig. 10(b)). Due to this, the initial conductance (air) would be relatively larger and in turn sensitivity would be smaller.

For the dipping time larger than the optimum, the number of Cr_2O_3 misfits would be larger. This would mask and resist the gas to reach the base material (BST) giving lower sensitivity.

6. Summary and Conclusions

1) The unmodified 2BST film is selective to NH_3 sensor at 350^oC.
2) The NH_3 gas response increases with the increase in film thickness and attains a maximum for 33 μm and response decreases on further increase in thickness.
3) The unmodified BST thick films were surface modified (Cr_2O_3-modified) using dipping technique.
4) The Cr_2O_3-modified BST sensor is selective to H_2S gas suppressing the responses to other gases.
5) The sensing properties of a particular material could be altered by surface modification.
6) The unmodified BST thick films were surface modified (Cr_2O_3-modified) using dipping technique.
7) The Cr_2O_3-modified BST sensor selective to H_2S gas suppressing the responses to other gases.

Acknowledgements

Authors are grateful to the Principal, Arts, Commerce and Science College, Nandgaon, Principal, K.T.H.M. College, Nashik, and also thankful to the Head of P.G. Department of Physics, Pratap College, Amalner for providing laboratory facilities, for his keen interest in this research project.

Author (GHJ) thankful to Dr. K.C. Mohite for his wholehearted co-operation in this research. Authors sincerely thank to B.C.U.D., University of Pune for financial assistance to this research project.

References

[1]. D. E. Williams, Semiconducting oxides as gas-sensitive resistors, *Sensors and Actuators B,* 57, 1999, pp. 1-16.
[2]. N. Barsan, M. Schweizer-Berberich, W. Göpel, Fundamental and practical aspects in the design of nano-scaled SnO_2 gas sensors, *Fresnius J. Anal. Chem.,* 365, 1999, pp. 287-304.
[3]. D. Kohl, Function and application of gas sensors, topical review, *J. Phys.,* D34, 2001, pp. R125-R149.
[4]. N. Docquier, S. Candel, Combustion control and sensors, a review, Progr. *Energy Combust. Sci.,* 28, 2002, pp. 107-150.
[5]. J. Riegel, H. Neumann, H. M. Wiedenmann, Exhaust gas sensors for automotive emission control, *Solid State Ionics,* 152/153, 2002, pp. 783-800.
[6]. P. K. Clifford, D. T. Tuma, Characteristics of semiconductor gas sensors I: steady state gas response, *Sensors and Actuators,* 3, 1983, pp. 233-254.
[7]. H. P. Huebner, S. Drost, Tin oxide gas sensors: An analytical comparison of gas-sensitive and non-gas-sensitive thin films, *Sensors and Actuators B,* 4, 1991, pp. 463-466.
[8]. R. K. Srivastava, P. Lal, R. Dwivedi, S. K. Srivastava, Sensing mechanism in tin oxide-based thick-film gas sensors, *Sensors and Actuators B,* 21, 1994, pp. 213-218.
[9]. G. Sberreglieri, Recent developments in semiconducting thin-film gas sensors, *Sensors and Actuators,* B23, 1995, pp. 103-109.
[10]. C. Imawan, F. Solzbacher, H. Steffs, E. Obermeier, Gas-sensing characteristics of modified-MoO_3 thin films using Ti-overlayers for NH_3 gas sensors, *Sensors and Actuators B,* 64, 2000, pp. 193-197.
[11]. K. Zakrzewska, Mixed oxides as gas sensors, *Thin solid films,* 391, 2001, pp. 229-238.
[12]. S. Saito, M. Miyayama, K. Koumoto, H. Yanagida, Gas sensing characteristics of porous ZnO and Pt/ZnO ceramics, *J. Am. Ceram. Soc.,* 68, 1, 1985, pp. 40-43.
[13]. H. Nanto, T. Minami, S. Takata, Zinc oxide thin film ammonia gas sensors with high sensitivity and excellent selectivity, *J. Appl. Phys.,* 60, 1986, pp. 482-484.
[14]. R. Sanjines, V. Dermane, F. Levy, Hall effect measurement in SnO_x film sensor exposed to reducing and oxidizing gases, *Thin solid films,* 193-194, 1990, pp. 935-942.
[15]. D. Manno, G. Micocci, R. Rella, A. Serra, A. Taurino, A. Tepore, Titanium oxide thin films for NH_3 monitoring: structural and physical characterization, *J. Appl. Phys.,* 82, 1, 1997, pp. 54-59.
[16]. P. T. Moseley, D. E. Williams, A selective ammonia sensor, *Sensors and Actuators B,* 1, 1990, pp. 113-115.
[17]. X. Wang, N. Miura, N. Yamazoe, Study of WO_3-based sensing materials for NH_3 and NO detection, *Sensors and Actuators B,* 66, 2000, pp. 74-76.
[18]. C. N. Xu, N. Miura, Y. Ishida, K. Matuda, N. Yamazoe, Study of WO_3-based sensing materials for NH_3 and NO detection, *Sensors and Actuators B,* 65, 2000, pp. 163-165.
[19]. M. Aslam, V. A. Choudhary, I. S. Mulla, S. R. Sainkar, A. B. Mandale, A. A. Belhekar, K. Vijaymohanan, Study of WO_3-based sensing materials for NH_3 and NO detection, *Sensors and Actuators A,* 75, 1999, pp. 162-167.
[20]. I. LundstrÖm, M. S. Shivaraman, C. M. Svensson, A hydrogen sensitive Pd-gate MOS transistor, *J. Appl. Phys.* 46, 1975, pp. 3876-3881.
[21]. T. Ishihara, K. Kometani, Y. Nishi, Y. Takita, Improved sensitivity of CuO-$BaTiO_3$ capacitance type CO_2 sensor, *Sensors and Actuators B,* 28, 1995, pp. 49-54.
[22]. Z. -T. Tang, Z. -G. Zhou, Z. -T. Zhang, Experimental studies on the mechanism of $BaTiO_3$ based PTC CO gas sensor, *Sensors and Actuators B,* 93, 2003, pp. 391-395.
[23]. Z. -G. Zhou, Z. -L Tang, Z. -T. Zhang, Studies on grain boundary chemistry pervoskite ceramics as CO gas sensors, *Sensors and Actuators B,* 93, 2003, pp. 356-361.
[24]. G. H. Jain, L. A. Patil, M. S. Wagh, D. R. Patil, S. A. Patil, D. P. Amalnerkar, Surface modified $BaTiO_3$ thick film resistors as H_2S gas sensors, *Sensors and Actuators B,* 117, 2006, pp. 159-165.
[25]. J. Holc, J. Slunečko, M. Hrovat, Temperature characteristics of electrical properties of (Ba,Sr)TiO_3 thick film humidity sensors, *Sensors and Actuators B,* 26-27, 1995, pp. 99-102.

[26]. X. F. Chen, W. G. Zhu, O. K. Tan, Microstructure, dielectric properties and hydrogen gas sensitivity of sputtered amorphous $Ba_{0.67}Sr_{0.33}TiO_3$ thin films, *Material Science and Engineering B,* 77, 2000, pp. 177-184.
[27]. W. Zhu, O. K. Tan, Q. Yan, J. T. Oh, Microstructure and hydrogen gas sensitivity of amorphous (Ba,Sr)TiO_3 thin film sensors, *Sensors and Actuators B,* 65, 2000, pp. 366-370.
[28]. S. Agarwal, G. L. Sharma, Humidity sensing properties of, Ba, Sr)TiO_3 thin films grown by hydrothermal-electrochemical method, *Sensors and Actuators B,* 85, 2002, pp. 205-211.
[29]. S. C. Roy, G. L. Sharma, M. C. Bhatnagar, S. B. Samanta, Novel ammonia-sensing phenomena in sol-gel derived $Ba_{0.5}Sr_{0.5}TiO_3$ thin films, *Sensors and Actuators B,* 110, 2005, pp. 299-303.
[30]. W. Yan, L. Sun, M. Lui, W. Li, Study of sensing characteristics of rare earth pervoskites for alcohol, *Acta Scientiarium Naturalium Universitaties Jilinesis,* 2, 1991, pp. 52-56.
[31]. L. Kong, Y. Shen, Gas sensing property of and mechanism of $Ca_xLa_{1-x}FeO_3$ ceramics, *Sensors and Actuators B,* 30, 1996, pp. 217-221.
[32]. G. H. Jain, L. A. Patil, Gas sensing properties of Cu and Cr activated BST thick films, *Bulletin of Material Science,* 29, 2006, pp. 403-411.
[33]. G. H. Jain, L. A. Patil, Gas Sensing Performance of Barium Strontium Titanate Thick Film Resistors, In *Proceedings of the 2nd International Conference on Sensing Technology (ICST '2007'),* Palmerston North, New Zealand, 26-28 November 2007, pp. 79-82.
[34]. T. Ishihara, K. Kometani, M. Hashida, Y. Takita, Application of mixed oxide capacitor to the selective carbon dioxide sensor, *J. Electrochem Soc.,* 138, 1991, pp. 173-175.
[35]. F. A. Cotton, G. Wilkinson, *Advanced Inorganic Chemistry*, Vol. 2, 2nd ed., Academic Press, New York, 1965, pp. 1347.

Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

Submission of papers

Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 6-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: http://www.sensorsportal.com/HTML/DIGEST/Submition.htm Authors must follow the instructions strictly when submitting their manuscripts.

Advertising Information

Advertising orders and enquires may be sent to sales@sensorsportal.com Please download also our media kit: http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2008.pdf