ISSN 1726-5479

SENSORS & TRANSDUCERS

vol. 107
8/09

Sensors and Transducers Applications

International Frequency Sensor Association Publishing

IFSA

Sensors & Transducers

Volume 107, Issue 8
August 2009

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 on CD.

Sensors & Transducers Journal

Contents

Volume 107
Issue 8
August 2009

www.sensorsportal.com

ISSN 1726-5479

Research Articles

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. 107, Issue 8, August 2009, pp. 99-110

www.sensorsportal.com

Sensors & Transducers

ISSN 1726-5479

http://www.sensorsportal.com

Sol Gel Synthesis of Tungsten Oxide Thin Film in Presence of Surfactant for NO_2 Detection

Vibha Srivastava, A. K. Srivastava, K. N. Sood, *Kiran Jain

Electronic Materials Division, National Physical Laboratory
Dr. K. S. Krishnan Marg, New Delhi, India
Tel.: 91-45608279, fax: 0091-11-25726938
E-mail: kiran@mail.nplindia.ernet.in

Received: 20 April 2009 /Accepted: 15 August 2009 /Published: 25 August 2009

Abstract: The sol–gel method was used to prepare WO_3 powder as well as film. The addition of block copolymer F 127 surfactant during synthesis resulted in a highly porous structure with reduced grain size. WO_3 thin films prepared without surfactant addition showed a lamellar structure on annealing at 350º C, while the surfactant - added samples showed spherical nodules. NO_2 gas response was enhanced for thin films prepared in presence of surfactant as compared to the films without surfactant. The film annealed at 600° C showed higher response magnitude as compared to 350º C annealed film. The gas response for a thick film was quite low as compared to thin film sensor derived through similar route. *Copyright © 2009 IFSA.*

Keywords: Oxides, Chemical synthesis, X-ray diffraction, Electrical properties

1. Introduction

NO_x gas is one of the most hazardous air pollutants and its detection is of great importance in both environmental protection and human health [1]. Semiconducting metal oxides such as WO_3 and SnO_2 have been widely used for NO_x detection [1, 2]. These sensors need to be operated at 200 - 500° C to improve the response by enhancing the chemical reaction between gas and the sensor material [3, 4]. WO_3 thin as well as thick film have been investigated for NO_x detection [1-14]. Thin film WO_3 sensors showed good selectivity, high sensitivity, fast response and recovery time for low concentrations of NO_x gas [6]. The sensitivity to NO_2 is higher than for NO, and catalysts that convert NO to NO_2 show high sensitivity towards NO_x. It has been reported that the sensitivity of the WO_3 thin films to NO_2

was enhanced by the addition of metals such as Au, Pd, Pt [7]. The gas sensing properties of these materials are influenced by various fabrications and processing conditions that affect the microstructure of the gas-sensing element. As gas adsorption occurs on the surface, an increase in the active surface area of the semiconductor oxide would enhance the properties of materials used as gas sensors. The surface to bulk ratio for a nanocrystalline material is much greater than for a material with large grains, which yields a large interface between the solid and a gaseous or liquid medium. In order to increase the active surface area, several synthetic routes have been used. Recently, much interest has developed in the chemical synthesis of materials in presence of surfactants [15-20]. The surfactant addition, during synthesis, works as structure directing agents to generate mesoporous materials. Cationic surfactant n-cetyltrimethylammonium bromide (CTAB) addition was used to synthesize SnO_2 [16]. Mesoporous WO_3 thin films with lamellar structure were synthesized by electrodeposition using SDS as a templating agent [17-18]. Mesostructured WO_3 was synthesized by means of hard template route from two silica templates: three-dimensional cubic (KIT –6) and two- dimensional hexagonal (SBA –15) structure and the introduction of copper as catalytic additive improved both sensor response and recovery time [19]. In a recent work, mesoporous WO_3 thin film have been synthesized by sol gel process using triblock copolymer surfactant as templates, the films showed high sensitivity even at temperatures as low as 50º C and detect low concentrations of NO_2 with high sensitivity [20]. A high surface area and small crystallite size present in the mesoporous WO_3 film was attributed to this high sensitivity.

In the present work, WO_3 films are derived by the sol gel route in the presence of surfactant, Pluronic F 127, and the annealing temperature was varied between 250 to 600º C to investigat the effect of annealing temperature on the NO_2 response characteristics. FTIR, XRD, TEM, SEM were used to characterize the material.

2. Experimental

Poly(alkylene oxide) block copolymer (Pluronic F127) was used as surfactant to prepare thin films as well as thick films. About 2.5 g of F127 copolymer was dissolved in 10 ml of ethanol. Then 1 g anhydrous tungsten chloride precursor, WCl_6 (Aldrich 99.9 %), was added into the F127 ethanol solution with vigorous stirring for 1 h. To prepare thin films, the resulting sol solution was coated over Al_2O_3 substrates that were pre-coated with Au electrodes for contacts by drop coating technique. The thin films were dried at 100°C, and annealed at 250 and 350º C for 4 h or at 600º C for 30 min; washed with ethanol to remove the residual block copolymer (WS). For comparison, films were similarly prepared without surfactant addition (W). For thick film sensor fabrication, the sol solution was heated at 60°C in air to dryness and calcined at 350º C for 4 h to obtain WO_3 powder. This powder was used to prepare thick films by screen-printing method and annealed at 600º C for 30 minutes.

WO_3 films were characterized by a variety of methods. Fourier transformed infrared spectroscopy (FTIR), in the range of 4000–400 cm^{-1}, were recorded on Perkin-Elmer Spectrum BX infrared spectrophotometer. X-ray powder diffraction (XRD) patterns were obtained on a BRUKNER AXS Power -X-ray diffractometer using Cu Kα radiation with Ni filter. High magnification nano-scale characterization was carried out employing a transmission electron microscope (TEM, model JEOL JFM 200x) operated at the electron accelerating voltage of 160 KV. The samples for TEM were prepared by directly dispersing the fine powders of the product onto 200 mesh Cu grids. The morphology of WO_3 films was observed by scanning electron microscope (SEM, LEO-440).

The resistance of the sensors was measured in air and in presence of NO_2 with a multimeter (Keithely-2000). The samples under test were placed in a test chamber (250 cm^3) and exposed to 1 ppm or 5 ppm NO_2 gas. Gas-sensing properties of the films were studied at various operating temperatures in

the range of 100° C to 300° C. The gas response S was defined as R_g/R_a, where R_g and R_a are the electrical resistances in test gas and air, respectively.

3. Results

3.1. Structure

In order to examine the effect of surfactant addition on the structural evaluation of WO_3 films, FTIR spectra were taken. Fig. 1 presents the FTIR spectra of WO_3 thin films annealed at 350° C with (WS) and without surfactant (W). The broad bands between 500 and 1000 cm^{-1} have been attributed to the framework vibrations of WO_3 [21, 22]. The thin film without surfactant (W) showed mainly two peaks present at 538 and 800 cm^{-1}, while WS showed the 538 peak shifted to 522 cm^{-1}; and the second peak split into two peaks at 780 and 842 cm^{-1}. Orel et al. [23] observed bands at (a) 880 cm^{-1} {ν(W–O_{inter}–W) bridging+ν (W–O–O–W) stretch}, (b) 798 cm^{-1} {ν(W–O_{intra}–W) bridging stretch and at (c) a deformational mode of W–O_{intra} at 555 cm^{-1} for films prepared by dip coating from a peroxotungstic acid sol. Hexagonal and monoclinic WO_3 films grown by anodic oxidation give rise to bands at 690 and 713 cm^{-1} which correspond to the W–O stretch [24]. Thus the peak present at 522 or 538 cm^{-1} can be assigned to the W-O stretching and other peak near 800 cm^{-1} is due to W-O-W stretching mode. No peaks were observed corresponding to surfactant or carbon after annealing the films at 350º C, indicating that the surfactant was completely removed and the sample was carbon-free.

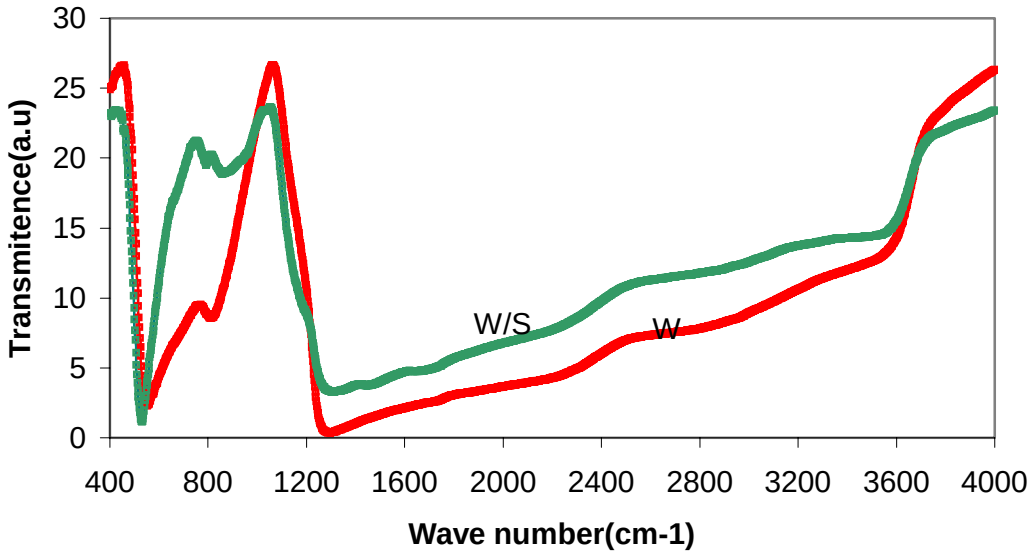


Fig. 1. FTIR spectra of samples after calcination at 350º C; (W) without surfactant (WS) with surfactant.

Fig. 2 (a) shows the XRD patterns for the WO_3 powder calcined at 350° C for 4 hours The XRD pattern for the powder prepared in presence of surfactant (WS) showed more broadening of the peaks as compared to that without surfactant addition (W). Fig.2 (b) shows the XRD pattern for thin films annealed at 600º C. The crystal structure of the films as well as powder showed a polycrystalline structure with all peaks belonging to monoclinic WO_3 phase (JCPDS No: 1043) and indexed accordingly. XRD peaks for the thick film are broadened as compared to the thin film.

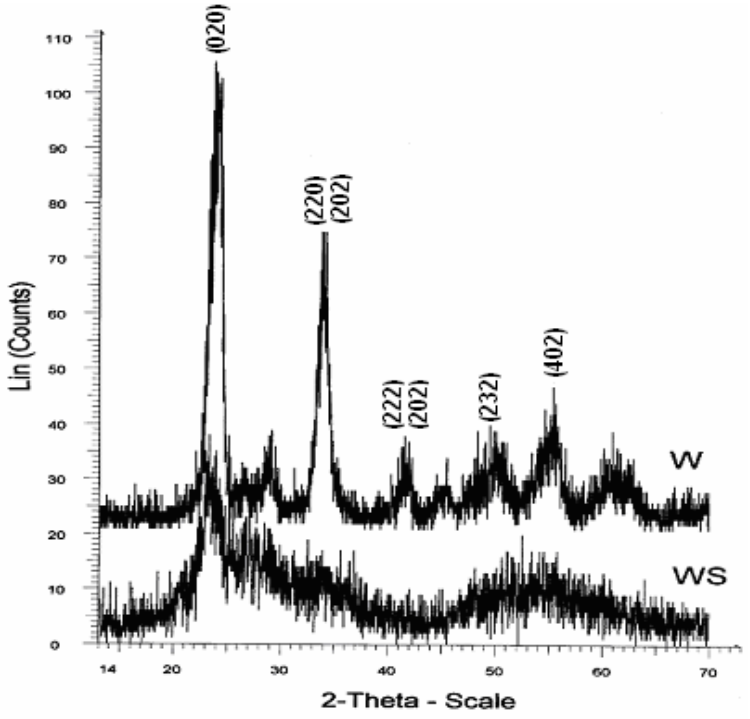


Fig. 2(a). XRD pattern for WO_3 powder calcined at 350˚ C for 4 h.

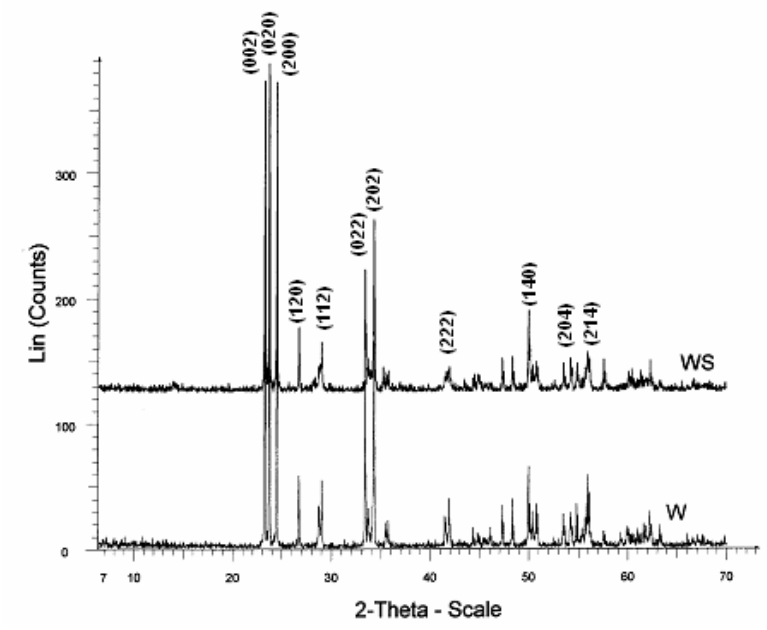
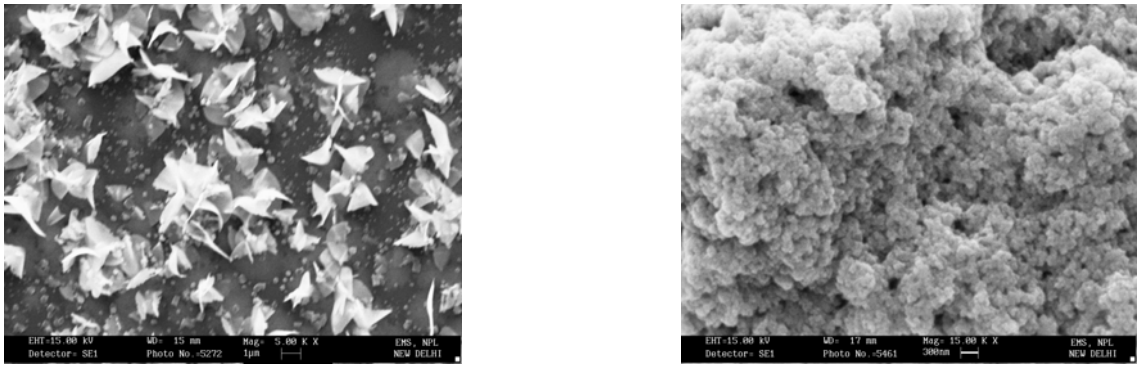


Fig. 2(b). XRD pattern for WO_3 thin films annealed at 600˚ C for 30 minutes.

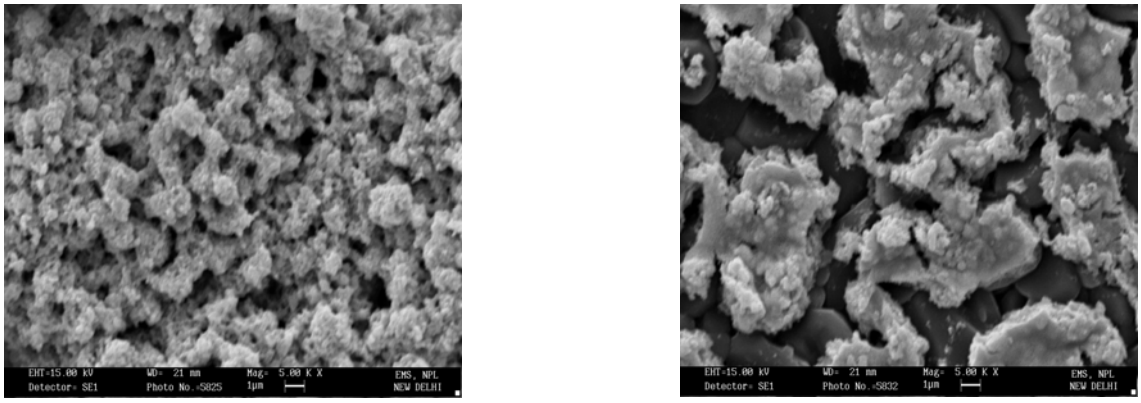
Fig. 3 (a, b) shows the SEM micrographs of the WO_3 thin films synthesized without surfactant and with surfactant respectively and annealed at 350° C. Sample prepared without surfactant consisted of large sheet like grains (>1μm) (lamellar structure) with some spherical granules. Most of these lamellas are not aligned in a particular direction; hence create a highly non-uniform and porous structure. In contrast, the sample prepared in presence of surfactant showed a more uniform, porous structure with spherical clusters of about 100 nm size. Such structure of nodular grain morphology with uniform sized nodules is likely to facilitate the adsorption process of NO_2 molecules because of the capillary pores and large surface area. In contrast, the lamellar morphology as shown in Fig. 3 (a),

consist of larger sized pores. Fig. 4 (a, b) shows the SEM micrographs of the WO_3 thin films annealed at 600° C. Sensor sample that was prepared without surfactant addition (Fig.4 a) showed large sized pores (~100 nm) as compared to the sample prepared in presence of surfactant (Fig.4 b). Fig.4 b shows a uniform structure with nodular grains, wherein nodules consist of small sized crystallites with small sized pores.



(a) (b)

Fig. 3. SEM micrograph of WO_3 thin film annealed at 350° C: (a) without surfactants, (b) with surfactants.

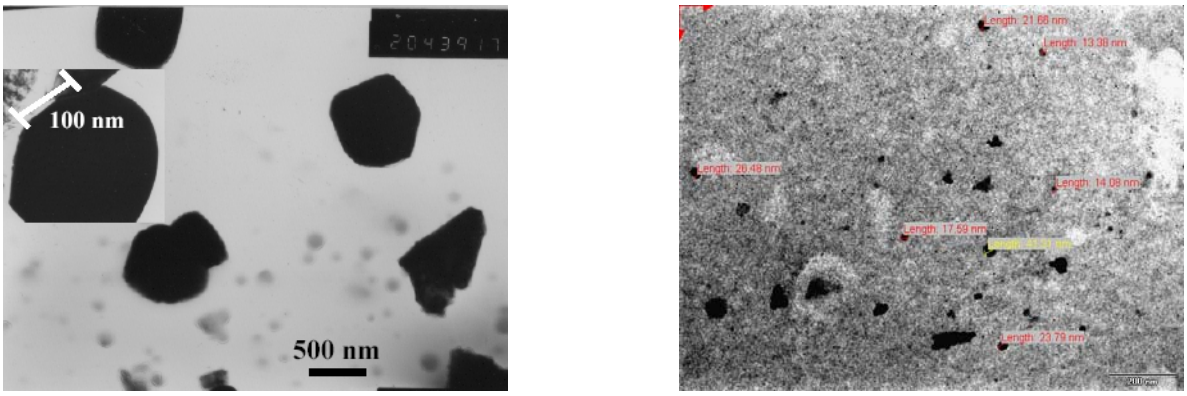


(a) (b)

Fig. 4. SEM micrograph of WO_3 thin film annealed at 600 °C: (a) without surfactants, (b) with surfactants.

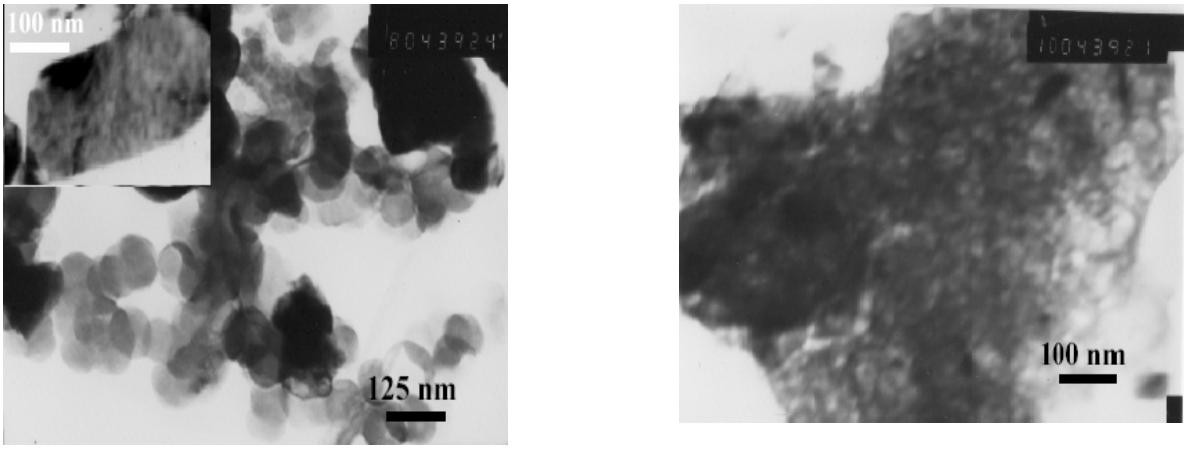
The TEM morphology of the WO_3 powders after calcinations at 350º C is shown in Figs. 5-6. The WO_3 without surfactants shows particles of different sizes. As shown in Fig.5 (a), large sized particles of about 300-500 nm in size (Fig. 5a) were present together with large number of small sized particles. The particles were well facetted with sharp edges, exhibiting crystalline nature of this material. Inset in Fig. 5(a) shows a magnified image of a particle with the size about 200 nm and the length of the edge is about 100nm. Fig. 5 (b) shows the TEM image of this sample in another region where smaller sized particles with a mean size of ~12-26 nm were clearly seen. The micro structural details from TEM support the information obtained in SEM Fig.3 (a), i.e., under this condition some large sized lamellas (100-200 nm size) are present together with small sized particles (12-26 nm size). The addition of surfactants during WO_3 formation leads to a more refined and porous structure (Fig. 6) as compared to bare WO_3 (Fig. 5). Surfactant – treatment of WO_3 material leads to ultrafine refined nano structure in two ways: (i) the individual nanoparticles are in size about 40-60 nm (Fig. 6a). Moreover these nanoparticles mostly consist of sub- nanoscaled refined microstructure (inset Fig. 6a); and (ii) the

larger size nanoparticles are constituted of cellular microstructure with ultrafine porosity (5-10 nm) distributed throughout the entire area of the specimen (Fig. 6a). Under these circumstances, the surfactant- added WO_3 has significantly larger surface area compared to the bare WO_3. Fig. 6(b) shows TEM image of surfactant- added WO_3 which reveals that the framework consist of meso-structured nanocrystals with particle size of ~3-9 nm (the image corresponds to WO_3 nanocrystals ~3 nm size) and agrees with the broadened peaks in XRD spectra as shown in Fig. 2.



(a) (b)

Fig. 5. TEM images of WO_3 powder (without surfactant) annealed at 350° C for 4 h.



(a) (b)

Fig. 6. TEM images of WO_3 powder (with surfactant) annealed at 350°C for 4 h.

3.2. Gas-sensing Properties

3.2.1 Thin Film

The response to NO_2 was measured on WO_3 films annealed at different temperature 250, 350 and 600°C. The response was measured at different temperatures - from 100 to 300°C towards NO_2 concentration of 1 and 5 ppm. The films that were annealed at 250ºC showed high resistance of the order of 100 Mohm to G ohm at 100-250°C in air, and increased on exposure to NO2. But the response was not reproducible; hence the results on this sample were not reported here. The response to 1 ppm and 5 ppm NO_2 at temperatures of 250°C and 300°C for WO_3 films annealed at 350ºC are

shown in Fig. 7. The sensor response increases when operating temperature is increased from 250 to 300ºC. The sensitivity was higher for surfactant - added sample.

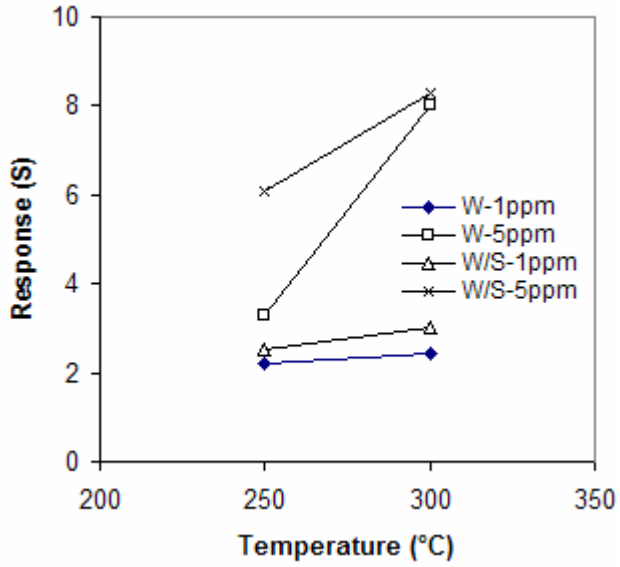


Fig. 7. Response Vs temperature for thin film annealed at 350ºC to 1 and 5 PPM NO_2.

Fig. 8 shows the gas response S vs. temperature plot for WO_3 thin films annealed at 600ºC for 30 minutes with surfactant (WS) and without surfactant (W), the gas response was measured between 100 to 300º C. Gas response to NO_2 increases on decreasing temperature. A large enhancement in gas response was observed for surfactant - added sample WS. A response of magnitude 62.5 was observed to 1 ppm NO_2 at 100ºC for surfactant- added sample. In an earlier report, WO_3 thin films prepared by DC magnetron sputtering and annealed at 600ºC for 4 hours were monoclinic and showed high sensitivity to low concentrations of NO_2 [12], similar to present results showing enhanced response for samples annealed at higher temperature. Further, the NO_2 response increased on decreasing the operating temperature. In contrast, the response and recovery times increased on increasing the operating temperature. At temperatures lower than 150ºC the sensors become too resistive in NO_2 atmosphere increasing the measurement noise and affecting reproducible data. Therefore 150º C is the best optimum temperature of NO_2 detection using such thin film sensors.

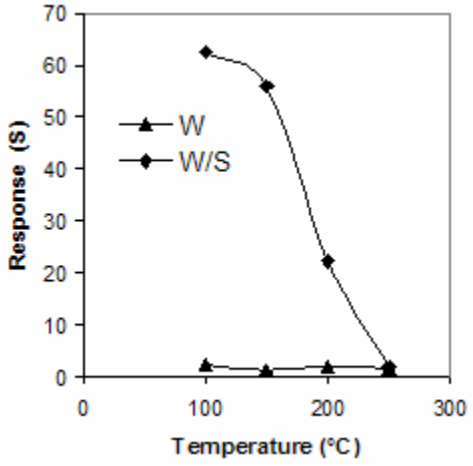


Fig. 8. Response Vs temperature for thin film annealed at 600ºC to 1 PPM NO_2.

3.2.2 Thick Film

Fig. 9 illustrates the gas response for thick film WO_3 sensors to 1 ppm NO_2 from 100 to 300°C. It is evident that the films are also able to detect 1 ppm of NO_2 in air at low temperature but the response was poor (100°C; S =13.8) in comparison to thin film sensor. These results (Fig. 6-9) show a systematic change of WO_3 response with decreasing operating temperatures; i.e. in general the response increases on decreasing operating temperature, with best response at 150ºC for thin film and 200ºC for thick film. More importantly, the results clearly show that a sample prepared in presence of surfactant has a much better response to low concentration of NO_2 gas. Thus, the sol- gel derived WO_3 thin film sensors in the presence of surfactant have the advantage of detection of low concentrations such as 1 ppm with response of about 60 and low operating temperature such as 150°C. In an earlier work, the effect of thickness was investigated and it was revealed that the sensors with film thickness of 0.6 μm showed excellent sensing properties to dilute NO_2 and that NO_2 response decreases steeply on increasing thickness [25]. The decrease in response for the thick film (~ 20 μm) sensor as compared to thin films observed in present work may be due to increased film thickness using screen printing method. These results suggest that even though the powder prepared in presence of surfactant is better for NO2 gas detection, the thin films are quite advantageous in enhancing the response drastically.

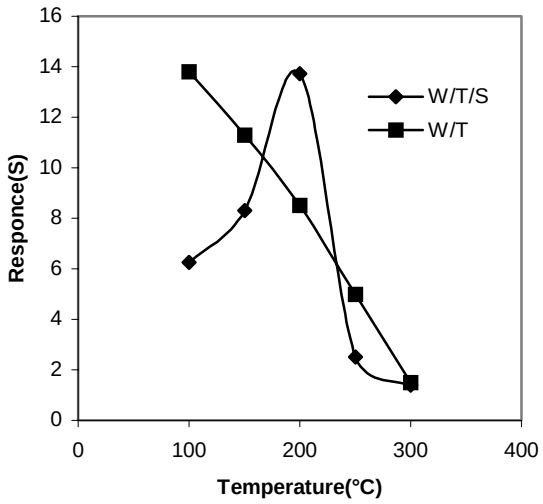


Fig. 9. Gas response Vs temperature thick film annealed at 600ºC to 1 ppm NO_2 with (W/T/S) and without surfactants (W/T).

3.2.3 Transient Response

Fig. 10 (a-c) shows the transient response curves for WO_3 thin film giving the best response, i.e., the prepared in presence of surfactant and annealed at 600° C. Fig. 10 (a) shows response curve for 1 and 5 ppm NO_2 measured at 250° C. Fig. 10(b) shows response curve for 1 and 5 ppm NO_2 measured at 300° C. Fig. 10 (c) shows response curve for 1ppm NO_2 measured at 150° C. As shown in figure, the response time was less than 1 minute at 200-300° C in thin film sensor, response time increased drastically on decreasing the temperature. The recovery time was about 5 minutes at 200 –300° C, but increased to 10-15 minutes at 150° C. At still lower temperatures even though response magnitude increased, but actual resistance was too high making measurements difficult, and the recovery time increased drastically.

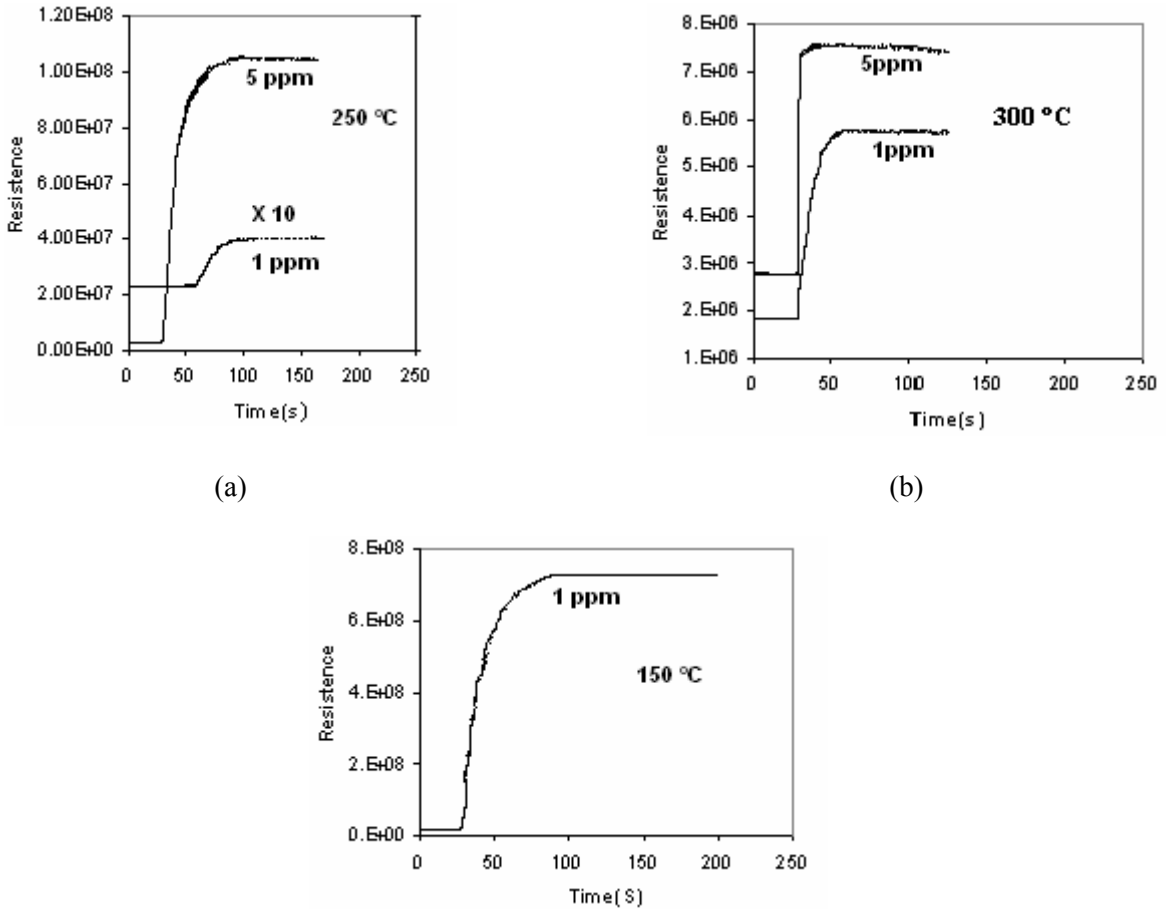


Fig. 10. Response curve for mesoporous WO_3 thin film sensor annealed at 600º C: (a) measured at 250° C, (b) measured at 300°C, (c) measured at 150° C.

Especially for atmospheric pollution detection, a low concentration of NOx detection is desired. As shown in Fig. 10 (c), surfactant - added WO_3 thin film sensor detected 1 ppm NO_X with a gas sensitivity of 35 at a temperature of 150° C. Even though this temperature is higher as compared to the mesoporous WO_3 thin film sensor reported earlier [26] where in gas detection at still lower temperature of 50-80° C was reported, but in the present work the sensitivity data at lower temperature were not obtained due to increase in recovery time at low temperatures and too high resistance that increases further in presence of NO_2.

Tungsten trioxide is an n-type semiconductor and belongs to the surface resistance controlled type sensor i.e. the sensor surface resistance changes on exposure to gaseous species. The sensor resistance decreases in the presence of reducing species (NH_3) and increases in the presence of oxidizing species (NO_2). Meso-structured materials are expected to provide heightened gas responses, as well as enhancing selectivity towards specific gases by tailoring the internal pore environment. Further, while there are many examples of tungsten trioxide meso-structure formation in the literature, there are few instances in which these materials were examined as sensor materials, mostly due to the difficulty in stabilizing the meso-structure upon surfactant removal. In the sol gel derived process in presence of surfactants, known as evaporation induced self-assembly EISA process, with solvent evaporation the concentration of the surfactant in the sol solution begins to exceed the critical micelle concentration and a self-assembly procedure is triggered [27]. The derived microstructure depends on the synthesis conditions. The crystallization of the material has been delayed by the presence of surfactant as compared to that in normal sol gel process, as revealed in Fig. 2 (a), which had shown a more

broadened XRD patterns for surfactant added samples. As had already been pointed out, the most important factors that influence the WO_3 sensor characteristics are probably the microstructure and surface area. The films prepared in presence of surfactant exhibit a mesoporous structure, having a large fraction of atoms residing at surfaces and interfaces between the pores, showed improvement in NO2 gas response. This suggests that such microstructures with small and uniform pores are suitable for gas-sensing purposes, if the pores are easily accessible to diffusion of gas. On the other hand, a microstructure, which consists of a matrix of small sized particles having a few large sized platelets, creates larger sized pores, that are not suitable for improving gas response. Further, for a long time operations of the sensors at operating temperatures of 150-200° C demand the sensor to be stabilized at high temperatures, and therefore in the present work we investigated the effect of annealing the sensors at 350 and 600° C. The response to NO_2 for the sensor annealed at 600° C and prepared in presence of surfactant is far better, as compared to that annealed at 350° C. On annealing the sensors at such high temperatures, the derived mesoporous structure might have collapsed, as we could not see any ordered arrangement of pores in the TEM/ SEM pictures. But the presence of surfactants during synthesis, that causes the formation of porous structure during the initial stages of firing, causes a decrease in grain size for the final product and enhances the surface area even after the removal of the surfactant, by keeping the grains apart during calcinations and sintering steps. Further the resulting microstructure was more uniform, with small sized pres. Better gas response observed for surfactant added WO_3 sensor samples as compared to sensors prepared without surfactant addition (even at very low temperature for NO_2) suggests that the higher response is most likely due to the smaller grain size and uniform small sized pores. Further the response for 600º C annealed film was higher as compared to film annealed at 350º C, which suggests that the crystallinity of the resulting WO_3 grains are also influencing the gas response.

The sensor response to NO_x has been reported to be dependent on the particle size of the WO_3 crystal, showing higher response with lowering of the size [28]. In another work, it has been reported that high annealing temperature leads to better NO_2 sensor response despite increased grain size in screen printed gas sensors based on SnO_2 nanopowders [29]. This was attributed to the improvement of the crystalline quality and the faceting of nanograins which improved NO_2 adsorption. The influence of thermal annealing on the microstructure and NO_2 sensing properties of WO_3 sensors revealed that thin films annealed at 500° C showed quickest response / recovery and highest response to 10 ppm NO_2 [30, 31]. Similar result on better gas response for a sensor annealed at higher temperature were reported earlier, i.e., a WO_3 gas sensor annealed at 700°C showed a better response to NO_2 in air than 400°C annealed WO_3 [32]. The formation of chemical bonds between gaseous species and metal oxides depends on the presence of unsaturated bonds on the surface of materials, so the amount of chemisorbed species increases with surface defect concentration. It was suggested that when annealing temperature increases over 400° C oxygen deficiencies may drift to the surface of the grains and become reactive sites for adsorption of NO_2 and oxygen molecules and thus improve sensor response. Apart from pore accessibility, crystallinity and oxygen deficiency also affect the sensor response. For example a change in oxygen stoichiometry leads to different sensor response [8]. Consequently the thermal treatment of films has a direct impact on the overall sensor response, and present results confirmed an improved response for a higher temperature (600° C) annealed sensor as compared to lower one (350° C).

In summary, NO_2 gas sensing measurements have been carried out to investigate the effect of surfactant on WO_3 thin films sensors annealed at different temperatures. The films showed monoclinic structure. The films annealed at 600° C and prepared in presence of surfactant, block polymer pluronic F127, showed quick response and highest response magnitude. These results highlight the importance of achieving porous structure for improving the gas sensor performance. Both 350 as well as 600º C annealed films are good sensing material to NO_2 and the response is quite low for thick film sensors as compared to the thin films derived through similar route.

4. Conclusions

Nanocrystalline WO_3 thin films were prepared at different temperatures by the sol–gel process in presence of block copolymer surfactant. The TEM microstructure revealed that the sol gel derived WO_3 powder in presence of surfactant is meso-structured having nanopores of size 5-7 nm. The sol gel derived WO_3 thin films in the presence of surfactant and annealed at 600˚ C showed enhanced sensing properties upon exposure to low concentration (1ppm) of NO_2. Fast Response and better response magnitude was observed in thin film sensor as compared to thick films. Thus the synthesis of WO_3 thin films in presence of block copolymer surfactants should be a promising technique for advanced miniaturized chemical sensors.

Acknowledgements

We are thankful to Dr. Y.K. Jain, CEERI Pilani for providing the sensor substrates. We are also thankful to Dr. S. K. Halder for measurement of XRD. One of the authors (VS) thanks Council of scientific and industrial research for the award of Research Associateship.

References

[1]. Y. Shimizu and M. Egashira, Basic aspects and challenges of semiconductor gas sensors, *MRS Bull.,* 24, 1999, pp. 18–24.
[2]. N. Yamazoe, N. Miura, Environmental gas sensing, *Sensors and Actuators*, 20, 1994, pp. 95-102.
[3]. H. T. Sun, C. Cantalini, L. Lozzi, M. Passacantando, S. Santucci, M. Pelino, Microstructural effect on NO_2 sensitivity of WO_3 thin film gas sensors. Part 1. Thin film devices, sensors and actuators, *Thin Solid Films,* 287, 1996, pp. 258–265.
[4]. Z. Ling, C. Leach, The effect of relative humidity on the sensitivity of a SnO2/WO_3 heterojunction gas sensors, *Sensors and Actuators B*, 102, 2004, pp. 102-106.
[5]. T. S. Kim, Y. B. Kim, K. S. Yoo, G. S. Sung, H. J. Jung, Sensing characteristics of DC reactive sputtered WO_3 thin films as an NO_2 gas sensor, *Sensors and Actuators B*, 62, 2000, pp. 102-108.
[6]. S. H. Wang, T. C. Choi, C. C. Liu, Nanocrystalline tungsten oxide NO_2 sensor, *Sensors and Actuators B*, 94, 2003, pp. 343-351.
[7]. G. Sberveglieri, L. Depero, S. Groppelli, P. Nelli, WO_3 sputtered thin films for NO_x monitoring, *Sensors and Actuators B*, 26-27, 1995, pp. 89-92.
[8]. S. Moulzolf, S. Ding, R. Lad, Stoichiometry and microstructure effects on tungsten oxide chemiresistive films, *Sensors and Actuators B*, 77, 2001, pp. 375-382.
[9]. C. Cantalini, H. T. Sun, M. Faccio, M. Pelino, S. Santucci, L. Lozzi, M. Passacantando, NO_2 sensitivity of WO_3 thin film obtained by high vacuum thermal evaporation*, Sensors and Actuators B*, 31, 1996, pp. 81-87.
[10]. M. Penza, C. Martucci, G. Cassano, NO_x gas sensing characteristics of WO_3 thin films activated by noble metals (Pd, Pt, Au) layers, *Sensors and Actuators B*, 50, 1998, pp. 52-59.
[11]. M. Akiyama, Z. Zhang, J. Amaki, N. Miura, N. Yamazoe, Tungsten oxide based semiconductor sensor for detection of nitrogen oxides in combustion exhaust, *Sensors and Actuators*, 14, 1993, pp. 619-20.
[12]. X. He, J. Li, X. Gao, L. Wang, NO_2 sensing characteristics of WO_3 thin film micro gas sensor, *Sensors and Actuators B*, 93, 2003, pp. 463-467.
[13]. D. Lee, J. Lim, S. Lee, J. Huh, D. Lee, Fabrication and characterization of microgas sensor for nitrogen oxides gas detection, *Sensors and Actuators B*, 64, 2000, pp. 31-36.
[14]. M. Akiyama, J. Tamaki, N. Miura and N. Yamazoe, Tungsten oxide-based semiconductor sensor highly sensitive to NO and NO_2, *Chem. Lett.,* 6, 1991, pp. 1611–1614.
[15]. C. T. Kresge, M. E. Leonowicz, W. J. Roth, J. C. Vartuli and J. S. Beck, Ordered mesoporous molecular sieves synthesized by a liquid-crystal template mechanism, *Nature*, 359, 1992, pp. 710–712.
[16]. G. J. Li and S. Kawi, High-surface-area SnO_2: a novel semiconductor-oxide gas sensor, *Mater. Lett*, 34, 1998, pp. 99–102.

[17]. S. Baeck, K. Choi, T. F. Jaramillo, G. D. Stucky, E. W. McFarland, Enhancement of photocatalytic and electrochromic properties of electrochemically fabricated mesoporous WO_3 thin films, *Adv Mater*, 15, 2003, pp. 1269-73.

[18]. M. Deepa, A. K. Srivastava, S. N. Sharma, Govind, S. M. Shivprasad, *J. Applied Surface Science,* 254, 2008, pp. 2342–2352.

[19]. E. Rossinyol, A. Prim, E. Pellicer, J. Rodriguez, F. Peiro, A. Cornet, J. R. Morante, B. Tian, T. Bo, D. Zhao, Mesostructured pure and copper catalyzed tungsten oxide for NO_2 detection, *Sensors and Actuators B*, 126, 2007, pp. 18-23.

[20]. L. G. Teoh, Y. M. Hon, J. Shieh, W. H. Lai, M. H. Hon, Sensitivity properties of a novel NO_2 gas sensor based on mesoporous WO_3 thin film, *Sensors and Actuators B*, 96, 2003, pp. 219-225.

[21]. I. M. F. Daniel, B. Desbat, J. C. Lassegues, B. Gerand and M. Figlaz, *J. Solid-State Chem*, 67, 1987, pp. 235.

[22]. L. H. M. Krings, W. Talen, Wet chemical preparation and characterization of electrochromic WO_3, *Solar Energy Mat. And Solar Cells*, 54, 1998, pp. 27-37.

[23]. B. Orel, N. Groselj, U. O. Krasovec and R. Jese, IR Spectroscopic Investigations of Gasochromic and Electrochromic Sol-Gel - Derived Peroxotungstic Acid/Ormosil Composite and CrystallineWO_3 Films, *Journal of Sol-Gel Science and Technology*, 24, 2002, pp. 5–22.

[24]. P. Delichere, P. Palaras, M. Froment, A. H. Goff, Electrochromism in anodic WO_3 films I: Preparation and physicochemical properties of films in the virgin and coloured states, *Thin Solid Films*, 161, 1988, pp. 35-46.

[25]. J. Tamaki, A. Hayashi, Y. Yamamoto, M. Matsuoka, Detection of dilute nitrogen dioxide and thickness effect of tungsten oxide thin film sensors, *Sensors and Actuators B*, 95, 2003, pp. 111-115.

[26]. L. G. Teoh, J. Shieh, W. H. Lai, I. M. Hung, M. H. Hon, Structure and optical properties of mesoporous tungsten oxide, *J. of Alloys and Compounds*, 396, 2005, pp. 251-254.

[27]. L. Wan, H. Fu, K. Shi, X. Tian, Simple synthesis of mesoporous alumina thin films, *Mat Let*., 62, 2008, pp. 1525-27.

[28]. J. Tamaki, Z. Zhang, K. Fujimori, M. Akiyama, T. Harada, N. Miura, N. Yamazoe, Grain size effects in tungsten oxide based sensor for nitrogen oxides, *J. Electrochem. Soc*., 141, 1994, pp. 2207-2210.

[29]. A. Dieguez, A. Romano-Rodríguez, J. L. Alay, J. R. Morante, N. Barsan, J. Kappler, U. Weimar and W. Göpel, Parameter optimization in SnO_2 gas sensors for NO_2 detection with low cross-sensitivity to CO: sol–gel preparation, film preparation, powder calcination, doping and grinding, *Sensors and Actuators B*, 65, 2000, pp. 166-168.

[30]. Y. K. Chung, M. H. Kim and W. S. Um, Gas sensing properties of WO_3 thick film for NO_2 gas dependent on process condition, *Sensors and Actuators B*, 60, 1999, pp. 49–56.

[31]. Z. Liu, T. Yamazaki, Y. Shen, T. Kikuta, N. Nakatani, Influence of annealing on microstructure and NO_2 sensing properties of sputtered WO_3 thin films, *Sensors and Actuators B*, 128, 2007, pp. 173-178.

[32]. I. Jimenez, J. Arbiol, G. Dezanneau, A. Cornet, J. R. Morante, Crystalline structure, defects and gas sensor response to NO_2 and H_2S of tungsten trioxide nanopowders, *Sens Actuators B*, 93, 2003, pp. 475-485.

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. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc.

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 8-14 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_2009.pdf