Ceramics International ■ (■■■■) ■■■–■■■

Contents lists available at ScienceDirect

Ceramics International

journal homepage: www.elsevier.com/locate/ceramint

Short communication

Mixed-potential type NO_x sensor using stabilized zirconia and MoO_3–In_2O_3 nanocomposites

Hao Cai, Ruize Sun *, Xue Yang, Xishuang Liang, Chong Wang, Peng Sun, Fengmin Liu, Chun Zhao, Yanfeng Sun, Geyu Lu *

State Key Laboratory on Integrated Optoelectronics, College of Electronic Science and Engineering, Jilin University, 2699 Qianjin Street, Changchun 130012, China

ARTICLE INFO

Article history:
Received 3 March 2016
Accepted 30 March 2016

Keywords:
YSZ
In_2O_3
MoO_3
Mixed-potential
NO_2 Sensor

ABSTRACT

Highly sensitive mixed-potential-type NO_2 sensors based on yttria-stabilized zirconia (YSZ) electrolyte and In_2O_3–MoO_3 nanocomposite electrode were fabricated. The In_2O_3 doped with 2%, 5%, 10% MoO_3 and pure In_2O_3 were synthesized by sol–gel method, and these materials were applied to sensing electrode (SE). The effects of doping amount of MoO_3 on NO_2-sensing properties were investigated. It was found that the sensor using In_2O_3 sensing electrode doped with 5 wt% MoO_3 exhibited larger sensitivity to NO_2 in the range of 10–200 ppm than the other sensors using In_2O_3 doped with 0%, 2% and 10% MoO_3. The sensor using In_2O_3 sensing electrode doped with 5% MoO_3 showed high sensitivity (59 mV/decade), good stable and repeatable performance at elevated temperature. The electric potential difference (ΔV) of the sensor varies almost linearly with the NO_2 concentrations in the examined range of 10–200 ppm. Moreover, it is noteworthy that the influence of relative humidity on NO_2 sensitivities at 500 °C is little. Combined with the XRD analysis, XPS analysis, ICP analysis of the sensing materials and modified-polarization curves of the sensors, it could be speculated that the MoO_3, doped to the In_2O_3 sensing electrode, plays a significant role in sensing performance, and a possible mechanism for the improvement of NO_2-sensing properties was proposed here.

1. Introduction

As the amount of vehicles increases fast and the modern industries develop rapidly, there is a strong concern about air pollution by the exhaust emission, which causes adverse results such as acid rains and photochemical smog in the environment ecosystem. In order to detect the NO_x emission from cars, high performance NO_x sensors are urgently demanded. Among the existing sensors, the mixed potential type NO_x sensors using yttria-stabilized zirconia (YSZ) captured people's attention and have been widely reported before [1–6].

The mixed potential type NO_x sensor using yttria stabilized zirconia (YSZ) and oxide electrode has been considered to be one of the best candidates for monitoring the exhaust emissions on account of its excellent durability, high temperature tolerance, chemical and mechanical stability, and low fabrication cost [7–14]. Many studies have focused on sensing electrode materials, device structure and sensing mechanism [15–34]. An army of metal oxides and mixed oxides, such as NiO [35], Cr_2O_3 [36], In_2O_3 [37] and $CdCrO_4$ [38], have been investigated in YSZ-based potentiometric sensors in some early researches. The use of the sensing electrode consisting of these oxides was reported to exhibit good sensitivity to NO_2, since they were considered to act as an electrochemical catalyst for the decomposition of NO_2. On the other hand, the doping of noble metal or other oxides to the oxide electrodes is an effective method to improve the sensing property. Miura et al. doped WO_3 [39], MoO_3 and Au [40] to the sensing electrode to improve the response and selectivity of the sensors. Inspired by these works, we decide to dope different amount of MoO_3 to In_2O_3 for improving the sensing property of In_2O_3.

In this work, we synthesized MoO_3–In_2O_3 as sensing electrode for YSZ-based potentiometric sensors, and the NO_2 sensing property was tested. The effects of the doping amount of MoO_3 on the NO_2-sensing property were investigated.

2. Experimental

MoO_3–In_2O_3 nanocomposites were prepared from their nitrates by sol–gel method, which could provide homogeneous mixing MoO_3–In_2O_3 nanocompites. In a typical synthesis process, $In(NO_3)_3$ and MoO_3 were dissolved in nitric acid. The molar ratio of In and

* Corresponding authors.
E-mail addresses: lugy@jlu.edu.cn (X. Liang), lugy@jlu.edu.cn (G. Lu).

http://dx.doi.org/10.1016/j.ceramint.2016.03.243
0272-8842/

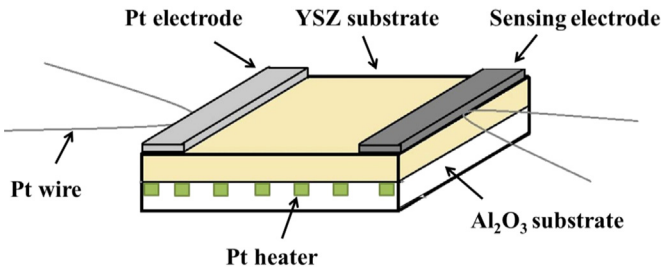

Fig. 1. Schematic structure of the sensor.

Mo was 9:1, 19:1 and 49:1, respectively. Then ethylene glycol was added to the above solution (the nitric acid/ethylene glycol volume proportion of 3:4). The resulting solution was maintained at 80 °C to form a polymeric gel. The polymeric gel was initially sintered at 350 °C for 2 h in the tubular furnace to remove the NO_3^-, and then sintered at 600 °C for 2 h to remove the polymer.

The schematic cross-sectional view of the planar sensor using YSZ and oxide electrode was shown in Fig. 1. The components, parameters and fabrication process of sensor as a traditional device structure was described in our previous paper [41]. The device was sintered at 550 °C in order to fit the sintering temperature (600 °C) of MoO_3–In_2O_3 nanocompites.

The obtained powder was characterized by XRD, XPS and ICP measurement. XRD patterns were tested by Rigaku wide-angle X-ray diffractometer (D/max rA, using Cu Kα radiation at wavelength=0.1541 nm). XPS (VG ESCA LAB MK II, Mg Kα, 10^{-7} Pa) was utilized to analyze the doped species in In_2O_3. Moreover, A Perkin-Elmer Optima-3000 was used to detect the chemical composition of the samples by inductively coupled plasma analysis (ICP).

The NO_2 sensing characteristics were measured with increasing NO_2 concentration from 10 ppm to 200 ppm (NO_2+21 vol% O_2+N_2 balanced) at the operating temperature of 550 °C. The electric potential difference between SE and RE was recorded by the digital electrometer (Digital Multimeter; Rigol Technologies, Inc., DM3054, China) as the testing signal.

The current-voltage (polarization) curves were measured by means of potentiodynamic method (Instrument corporation of Shanghai, China, CHI600 C) at a constant scan-rate of 3 mV/min using a two-electrode configuration in the base gas (21 vol% O_2+N_2 balance) and the sample gas (20 and 50 ppm NO_2+21 vol% O_2+N_2 balance). The current axis of the anodic polarization curve was subtracted from that of the cathodic polarization curve at each potential so as to obtain the modified polarization curve.

3. Results and discussion

Fig. 2 shows the XRD patterns of samples In_2O_3 doped with 2%, 5% and 10% MoO_3, respectively. It could be easily seen that all the diffraction peaks of each sample were indexed to In_2O_3 (JCPDS PDF # 65-3170). However, there is no obvious diffraction peak indexed to MoO_3. One reason for this is the low molecular proportion of MoO_3. In addition, the low sintering temperature might lead poor crystallinity of MoO_3. For the above reasons, the MoO_3 showed no obvious diffraction peak.

In order to verify the existence of Mo^{6+}, XPS was applied for measuring the In_2O_3 powders doped with 2%, 5% and 10% MoO_3, respectively, as shown in Fig. 3. As a result, it was found that the the strongest peak of Mo3d3/2 appeared at 232.9 eV and 235.9 eV, which accords with that of MoO_3 and Mo^{6+}, respectively. Moreover, with the ICP technique, the amounts of In and Mo in the samples were determined, and the result was shown in Table 1. By calculation, the molecular proportion of MoO_3 is 2.3%, 5.2% and

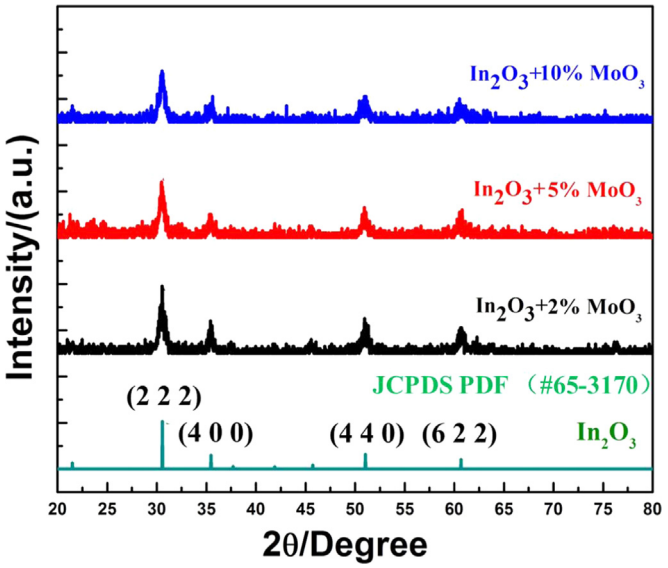

Fig. 2. XRD pattern of NiO powders doped with 2%, 5% and 10% MoO_3, respectively.

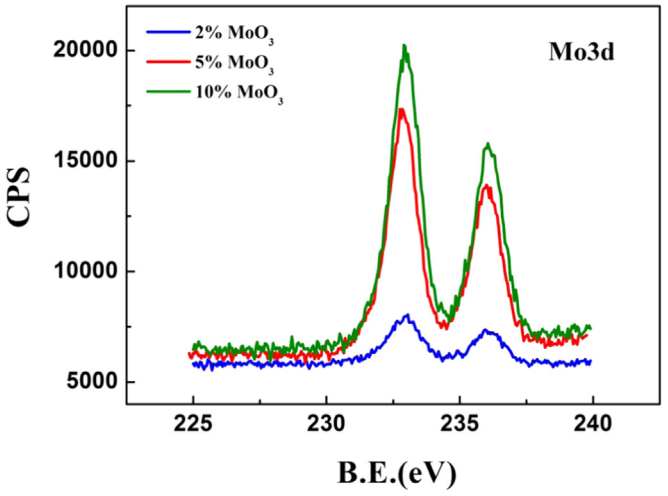

Fig. 3. XPS spectra of samples doped with 2%, 5% and 10% MoO_3, respectively.

Table 1
Sample analysis of results (mg/L).

	Mean concentration (In)	Mean concentration (Mo)
Sample 1	134 mg/L	2.79 mg/L
Sample 2	140 mg/L	6.77 mg/L
Sample 3	118 mg/L	9.93 mg/L

8.8%, respectively, which is close to the proportion of the material input.

The response transients of the sensors attached with In_2O_3 doped with 2%, 5%, 10% MoO_3 and pure In_2O_3 to various NO_2 concentrations were exhibited in Fig. 4. The operating temperature for these sensors was set to 500 °C. It could be seen that the sensor attached with In_2O_3 doped with 5% MoO_3 as sensing electrode have highest electric potential difference (ΔV) (electric potential difference (V_{NO2})−electric potential difference (V_{air})) and the ΔV of this sensor to 100 ppm NO_2 is 101 mV, which is about 1.19, 1.51 and 1.35 times higher than those for the sensors doped with 2% MoO_3, 10% MoO_3 and no doped, respectively.

The dependence of ΔV on the logarithm of NO_2 concentration

Please cite this article as: H. Cai, et al., Mixed-potential type NO_x sensor using stabilized zirconia and MoO_3–In_2O_3 nanocomposites, Ceramics International (2016), http://dx.doi.org/10.1016/j.ceramint.2016.03.243

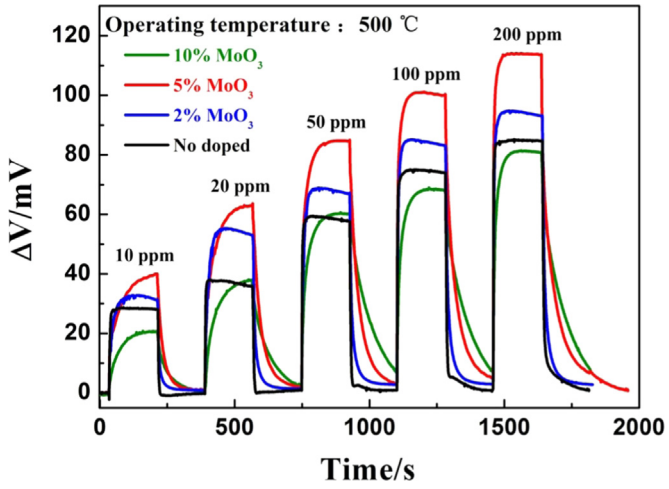

Fig. 4. Response transients of the sensors attached with In_2O_3 which was doped with 2%, 5%, 10% MoO_3 and pure In_2O_3 to various NO_2 concentrations in the range from 10 ppm to 200 ppm at 500 °C.

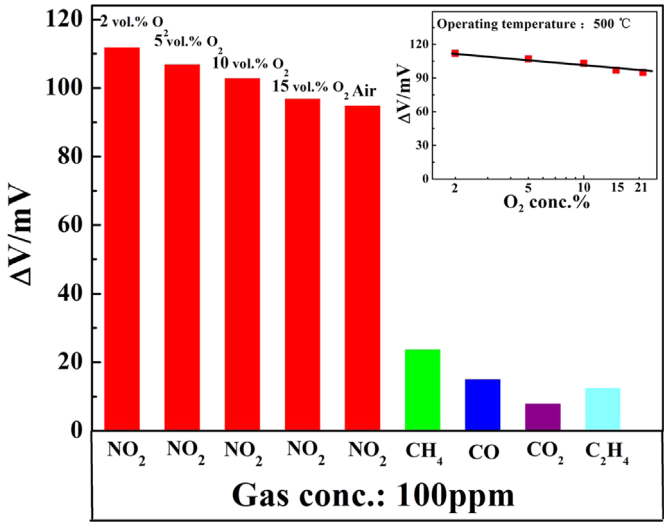

Fig. 6. Cross-sensitivities to various gases and dependence of the ΔV on the logarithm of O_2 concentrations for the sensor attached with 5% MoO_3-SE at 500 °C.

for sensor doped with 5% MoO_3 and no doped was also shown in Fig. 5a. The ΔV values are almost linear to the logarithm of NO_2 concentration. The slope is promoted from 47 mv/decade (for no doped ones) to 59 mv/decade (for doped with 5% MoO_3 ones). The continuous response-recovery transients (Fig. 5b) show the stable and repeatable performance of sensor doped with 5% MoO_3. By calculation, the mean squared error of these continuous responses to 100 ppm NO_2 was 0.745 mV, which indicated that sensor doped with 5% MoO_3 showed superior repeatability. In addition, the response for the sensor attached with 5% MoO_3-SE to 100 ppm NO_2 in the relative humidity range of 15–100% at 500 °C was measured and the results obtained are shown in Fig. 5c. It can be seen that the effect of relative humidity on the response of the sensor is small in the examined range.

Furthermore, the cross-sensitivities of the sensor doped with 5% MoO_3 is shown in Fig. 6. It can be observed that the sensor

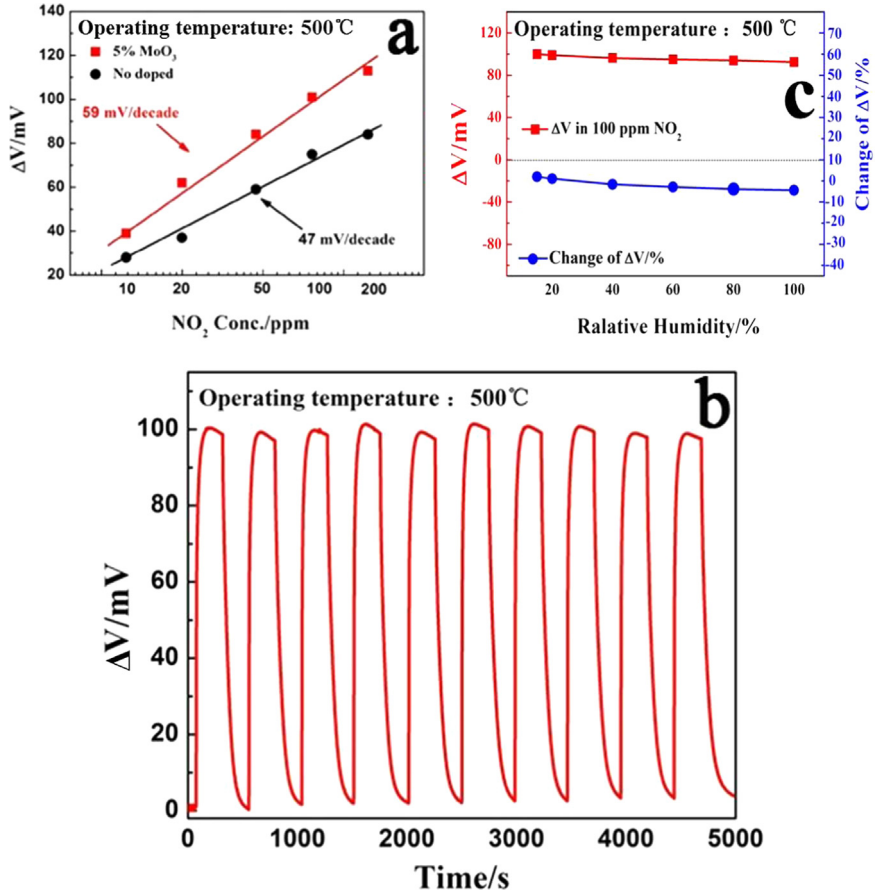

Fig. 5. (a) The dependence of the ΔV on the logarithm of NO_2 concentrations for sensor attached with In_2O_3 doped with 5% MoO_3 and pure In_2O_3, (b) continuous response-recovery transients of sensor attached with In_2O_3 doped with 5% MoO_3 to 100 ppm NO_2 at 500 °C, (c) the response for the sensor attached with 5% MoO_3-SE to 100 ppm NO_2 in the relative humidity range of 15–100% at 500 °C.

Please cite this article as: H. Cai, et al., Mixed-potential type NO_x sensor using stabilized zirconia and MoO_3–In_2O_3 nanocomposites, Ceramics International (2016), http://dx.doi.org/10.1016/j.ceramint.2016.03.243

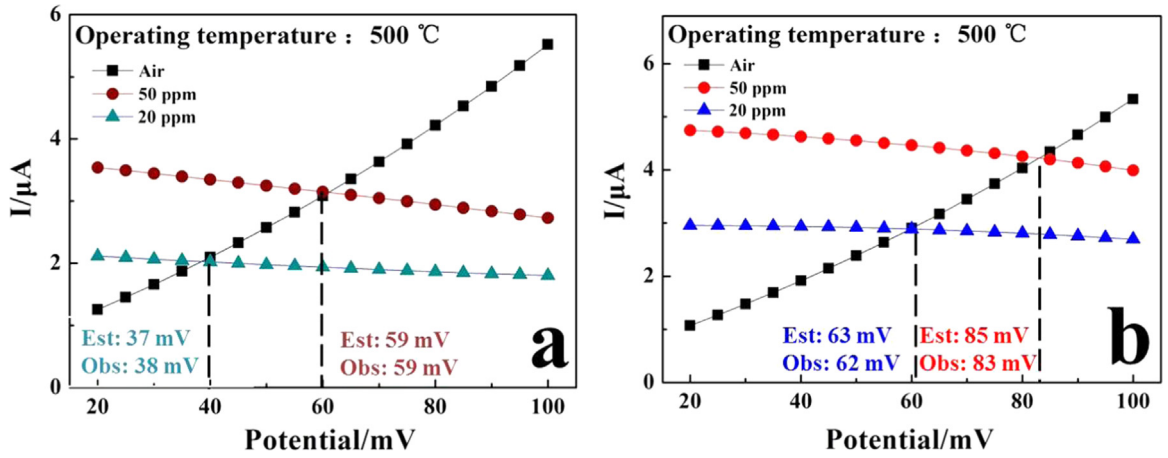

Fig. 7. Polarization curves recorded in air, in 20 and 50 ppm NO_2 at 500 °C for (a) sensors attached with pure In_2O_3 and (b) sensors attached with In_2O_3 doped with 5% MoO_3.

shows favorable selectivity to NO_2 among other gases which may exist in vehicle's exhaust. Responses of the sensor utilizing 5% MoO_3-SE to 100 ppm NO_2 at different concentrations of O_2 at 500 °C were measured and shown in Fig. 6. It can be seen that the response to 100 ppm NO_2 for the sensor decreased with the increasing of oxygen partial pressure, and the response was almost linear to the logarithm of O_2 concentrations. Therefore, this result could be regarded as an evidence for the mixed-potential potential theory, the reasons were discussed in the following.

The mechanism of mixed-potential-type zirconia-based NO_2 sensor has been reported in our earlier work [41,42]. This sensing mechanism could be described by the following electrochemical cells:

In air: O_2, In_2O_3 /YSZ/Pt, O_2
In sample gas: $O_2 + NO_2$, In_2O_3 /YSZ/Pt, $NO_2 + O_2$

In air, the electrons in the equilibrium transferred between electrodes and YSZ. At sensing electrode (SE) and reference electrode (RE), the equilibrium took place at different rates, inducing an electric potential difference (V_{air}) between SE and RE. For the case of the insensitivity of RE to NO_2, the potential of RE was fixed by constant O_2 concentration under the coexistence of NO_2 and O_2. On the other side, due to SE's high electrochemistry catalytic activity to NO_2, the potential of SE could be changed by NO_2 and a local cell was formed at the sensing electrode by the following electrochemical reactions:

Cathodic: $NO_2 + 2e^- \rightarrow NO + O^{2-}{}_{(YSZ)}$
Anodic: $2O^{2-}{}_{(YSZ)} \rightarrow O_2 + 4e^-$

When the rates of the two electrochemical reactions were equal, the potential of SE was the so-called mixed-potential. The electric potential difference between SE and RE was V_{NO2}. The response for this kind of sensor to NO_2 was depended on the rate of the cathodic and anodic electrochemistry reactions occurred on three-phase boundary (TPB). In this case, the sensor attached with In_2O_3 doped with 5% MoO_3 gave larger response to NO_2, implying that the In_2O_3 doped with 5% MoO_3 gave fairly high electrochemistry catalytic activity to the reaction occurred on TPB.

For further investigating the mechanism of the improvement of the electrochemistry catalytic activity, the modified polarization curves of the sensor attached with 5% MoO_3–In_2O_3 and pure In_2O_3 as sensing electrodes were shown in Fig. 7. Both of the sensors were measured in 20 ppm NO_2, 50 ppm NO_2 and air. The anodic polarization curve was obtained in air, and the cathodic polarization curve was obtained by subtracting the one in air from the one in NO_2+air. The mixed-potential can be estimated from the intersection of the anodic and cathodic polarization curves. It can be seen that the sensor attached with 5% MoO_3–In_2O_3 as sensing electrode shows larger catalytic activity for the cathodic electrochemical reaction than the sensor attached with pure In_2O_3-SE, leading to a larger potential value. Hence, it is reasonable to believe that the response of the sensor to NO_2 is enhanced by the addition of MoO_3 to In_2O_3, due to the comparative increasement on catalytic activity for the cathodic electrochemical reaction. Moreover, the mixed potentials estimated by intersecting the anodic polarization curve with the cathodic polarization curve were in good agreement with the measured ΔV values, which confirms a new evidence for that the present sensors are working based on the mixed-potential mechanism.

4. Conclusions

In this work, the MoO_3–In_2O_3 SE layer was formed on the YSZ plate. It is found that the sensor attached with 5% MoO_3–In_2O_3 as sensing electrode has the highest sensitivity among the sensors doped with 0%, 2% and 10% MoO_3 in molecular proportion. Further tests were taken with a concentration range of 10–200 ppm, and agree with the linear relationship between the response and logarithm of the concentration. The selectivity and repetitiveness tests have been carried out and the results are promising. The high sensitivity could be attributed to the increasement on catalytic activity for the cathodic electrochemical reaction. These positive sensing performances indicate that the sensor using 5% MoO_3–In_2O_3 has potential application in car emission control system.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (61520106003, 61134010, 61327804, 61304242, 61377058, 61473132 and 61374218) and Program for Chang Jiang Scholars and Innovative Research Team in University (No. IRT13018). National High-Tech Research and Development Program of China (863 Program, No. 2014AA06A505).

References

[1] G. Lu, N. Miura, N. Yamazoe, Stabilized zirconia-based sensors using WO_3 electrode for detection of NO or NO_2, Sens. Actuators B: Chem 65 (2000)

125–127.
[2] R. Moos, K. Sahner, M. Fleisc, her, U. Guth, N. Barsan, N. Barsan, U. Weimar, Solid state gas sensor research in Germany – a status report, Sensors 9 (2009) 4323–4365.
[3] G. Lu, Q. Diao, C. Yin, S. Yang, Y. Guan, X. Cheng, X. Liang, High performance mixed-potential type NO_x sensor based on stabilized zirconia and oxide electrode, Solid State Ion. 136 (2000) 519–531.
[4] P. Sekhar, E. Brosha, R. Mukundan, W. Li, M. Nelson, P. Palanisamy, F. Garzon, Application of commercial automotive sensor manufacturing methods for NO_x /NH_3 mixed potential sensors for on-board emissions control, Sens. Actuators B: Chem. 144 (2010) 112–119.
[5] F. Liu, Y. Guan, R. Sun, X. Liang, P. Sun, F. Liu, G. Lu, Mixed potential type acetone sensor using stabilized zirconia and $M_3V_2O_8$ (M: Zn, Co and Ni) sensing electrode, Sens. Actuators B: Chem. 147 (2010) 780–785.
[6] S. Fischer, R. Pohle, M. Fleischer, R. Moos, Method for reliable detection of different exhaust gas components by pulsed discharge measurements using standard zirconia based sensors, Sens. Actuators B: Chem 1 (2009) 585–588.
[7] N. Miura, G. Lu, N. Yamazoe, H. Kurosawa, M. Hasei, Mixed potential type NO_x sensor based on stabilized zirconia and oxide electrode, J. Electrochem. Soc. 143 (1996) L33–L35.
[8] N. Miura, H. Kurosawa, M. Hasei, G. Lu, N. Yamazoe, Stabilized zirconia-based sensor using oxide electrode for detection of NOx in high-temperature combustion-exhausts, Solid State Ion. 86 (1996) 1069–1073.
[9] T. Hibino, K. Ushiki, Y. Kuwahara, Electrochemical oxygen pump using CeO_2-based solid electrolyte for NO_x detection independent of O_2 concentration, Solid State Ion. 93 (1997) 309–314.
[10] E.L. Brosha, R. Mukundan, D.R. Brown, F.H. Garzon, Mixed potential sensors using lanthanum manganate and terbium yttrium zirconium oxide electrodes, Sens. Actuators B: Chem. 87 (2002) 47–57.
[11] N.F. Szabo, P.K. Dutta, Correlation of sensing behavior of mixed potential sensors with chemical and electrochemical properties of electrodes, Solid State Ion. 171 (2004) 183–190.
[12] U. Guth, J. Zosel, Electrochemical solid electrolyte gas sensors-hydrocarbon and NO_x analysis in exhaust gases, Ionics 10 (2004) 366–377.
[13] N. Miura, J. Wang, M. Nakatou, P. Elumalai, M. Hasei, NO_x sensing characteristics of mixed-potential-type zirconia sensor using NiO sensing electrode at high temperatures, Electrochem. Solid-State Lett. 8 (2005) H9–H11.
[14] P. Elumalai, J. Wang, S. Zhuiykov, D. Terada, M. Hasei, N. Miura, Sensing characteristics of YSZ-based mixed-potential-type planar NO_x sensors using NiO sensing electrodes sintered at different temperatures, J. Electrochem. Soc. 152 (2005) H95–H101.
[15] S. Zhuiykov, Mathematical modelling of YSZ-based potentiometric gas sensors with oxide sensing electrodes, Sens. Actuators B: Chem. 120 (2007) 645–656.
[16] S. Zhuiykov, Mathematical modelling of YSZ-based potentiometric gas sensors with oxide sensing electrodes, Sens. Actuators B: Chem. 119 (2006) 456–465.
[17] C. López-Gándara, J.M. Fernández-Sanjuán, F.M. Ramos, A. Cirera, Role of nanostructured WO_3 in ion-conducting sensors for the detection of NO_x in exhaust gases from lean combustion engines, Solid State Ionics 184 (2011) 83–87.
[18] E.N. Armstrong, T. Striker, V. Ramaswamy, J.A. Ruud, E.D. Wachsman, NO_x adsorption behavior of $LaFeO_3$ and LaMnO3+(and its influence on potentiometric sensor response, Sens. Actuators B: Chem. 158 (2011) 159–170.
[19] V.V. Plashnitsa, P. Elumalai, Y. Fujio, N. Miura, Zirconia-based electrochemical gas sensors using nano-structured sensing materials aiming at detection ofautomotive exhausts, Electrochim. Acta 54 (2009) 6099–6106.
[20] H. Jin, V.V. Plashnitsa, M. Breedon, N. Miura, Compact YSZ-rod-based hydrocarbon sensor utilizing metal-oxide sensing-electrode and Mn-based reference-electrode combination, Electrochem. Solid-State Lett. 14 (2011) J23.
[21] S.P. Mondal, P.K. Dutta, G.W. Hunter, B.J. Ward, D. Laskowski, R.A. Dweik, Development of high sensitivity potentiometric NO_x sensor and its application to breath analysis, Sens. Actuators B: Chem. 158 (2011) 292–298.
[22] J. Gao, J.-P. Viricelle, C. Pijolat, P. Breuil, P. Vernoux, A. Boreave, A. Giroir-Fendler, Improvement of the NO_x selectivity for a planar YSZ sensor, Sens. Actuators B: Chem. 154 (2011) 106–110.
[23] X. Liang, S. Yang, J. Li, H. Zhang, Q. Diao, W. Zhao, G. Lu, Mixed-potential type zirconia-based NO_2 sensor with high-performance three-phase boundary, Sens. Actuators B: Chem. 158 (2011) 1–8.
[24] A. Lari, A. Khodadadi, Y. Mortazavi, Semiconducting metal oxides as electrode material for YSZ-based oxygen sensors, Sens. Actuators B: Chem. 139 (2009) 361–368.
[25] N. Miura, H. Jin, R. Wama, S. Nakakubo, P. Elumalai, V.V. Plashnitsa, Novel solid-state manganese oxide-based reference electrode for YSZ-based oxygen sensors, Sens. Actuators B: Chem. 152 (2011) 261–266.
[26] J. Yoo, S. Chatterjee, F.M. Van Assche, E.D. Wachsman, Influence of adsorption and catalytic reaction on sensing properties of a potentiometric La_2CuO_4/YSZ/Pt sensor, J. Electrochem. Soc. 154 (2007) J190.
[27] F.M. Van Assche IV, E. Wachsman, Isotopically labeled oxygen studies of the NO_x exchange behavior of La_2CuO_4 to determine potentiometric sensor response mechanism, Solid State Ion. 179 (2008) 2225–2233.
[28] F.M. Van Assche, J.C. Nino, E.D. Wachsman, X-Ray photoemission spectroscopy of adsorbates on La_2CuO_4 to determine potentiometric NO_x sensor response mechanism, J. Electrochem. Soc. 155 (2008) J198.
[29] B. White, E. Traversa, E. Wachsman, Investigation of La_2CuO_4/YSZ/Pt potentiometric NO_x sensors with electrochemical impedance spectroscopy, J. Electrochem. Soc. 155 (2008) J11.
[30] J.C. Yang, P.K. Dutta, High temperature potentiometric NO_2 sensor with asymmetric sensing and reference Pt electrodes, Sens. Actuators B: Chem. 143 (2010) 459–463.
[31] N. Szabo, P. k Dutta, Correlation of sensing behavior of mixed potential sensors with chemical and electrochemical properties of electrodes, Solid State Ion. 171 (2004) 183–190.
[32] M.L. Grilli, E. Di Bartolomeo, E. Traversa, Electrochemical NO_x sensors based on interfacing nanosized $LaFeO_3$ perovskite-type oxide and ionic conductors, J. Electrochem. Soc. 148 (2001) H98–H102.
[33] E. Di Bartolomeo, M.L. Grilli, E. Traversa, Sensing mechanism of potentiometric gas sensors based on stabilized zirconia with oxide electrodes, J. Electrochem. Soc. 151 (2004) H133.
[34] A.M. Azad, Solid-state gas sensors: a review, J. Electrochem. Soc. 139 (1992) 3690.
[35] P. Elumalai, J. Zosel, U. Guth, N. Miura, NO_2 sensing properties of YSZ-based sensor using NiO and Cr-doped NiO sensing electrodes at high temperature, Ionics 15 (2009) 405–411.
[36] J. Yoo, E.D. Wachsman, NO_2/NO response of Cr_2O_3- and SnO_2-based potentiometric sensors andtemperature-programmed reaction evaluation of the sensor elements, Sens. Actuators B: Chem. 123 (2007) 915–921.
[37] H. Jin, M. Breedon, N. Miura, Sensing behavior of YSZ-based amperometric NO_2 sensors consisting of Mn-based reference-electrode and In_2O_3 sensing-electrode, Talanta 88 (2012) 318–323.
[38] N. Miura, G. Lu, N. Yamazoe, High-temperature potentiometric: amperometric NO_x sensors combining stabilized zirconia with mixed-metal oxide electrode, Sens. Actuators B: Chem. 52 (1998) 169–178.
[39] N. Miura, J. Wang, P. Elumalai, T. Ueda, D. Terada, M. Hasei, Improving NO_2 sensitivity by adding WO_3 during processing of NiO sensing-electrode of mixed-potential-type zirconia-based Sensor, J. Electrochem. Soc. 154 (2007) J246–J252.
[40] C.N. Xu, N. Miura, Y. Ishida, K. Matsuda, N. Yamazoe, Selective detection of NH_3 over NO in combustion exhausts by using Au and MoO doubly promoted WO_3 element, Sens. Actuators B: Chem. 65 (2000) 163–165.
[41] Q. Diao, C. Yin, Y. Liu, J. Li, G. Xun, X. Liang, S. Yang, H. Chen, G. Lu, Mixed-potential-type NO_2 sensor using stabilized zirconia and Cr_2O_3–WO_3 nanocomposites, Sens. Actuators B: Chem. 180 (2013) 90–95.
[42] C. Yin, Y. Guan, Z. Zhu, X. Liang, B. Wang, Q. Diao, H. Zhang, J. Ma, F. Liu, Y. Sun, J. Zheng, G. Lu, Highly sensitive mixed-potential-type NO_2 sensor using porous double-layer YSZ substrate, Sens. Actuators B: Chem. 183 (2013) 474–477.

Please cite this article as: H. Cai, et al., Mixed-potential type NO_x sensor using stabilized zirconia and MoO_3–In_2O_3 nanocomposites, Ceramics International (2016), http://dx.doi.org/10.1016/j.ceramint.2016.03.243