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A Phenomenological Analysis of MEMS-Based Sensor for Toxic Gas Sensing in Coal Mine

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Abstract

In coal mine different types of toxic gases are present. There is an increasing demand on toxic gas sensor for coal mine where the power consumption is a big issue. In this paper a simple structure of micro heater and inter digited electrode has been fabricated and micro machined structure for low power consumption is demonstrated. MEMS microheaters are designed and fabricated for entire two inch (2") process and 3mm X 3mm die sized microheaters obtained.

Keywords: Gas sensor; Micro Electro Mechanical System (MEMS); Micro machined.

Introduction

Detection of toxic gases by using different sensing techniques are used for commercial application. Conventional sensor used either short life electrochemical types or long life figuro types but it consumes large power [1]. These types are unacceptable for continuous gas monitoring in underground coalmines for which considerable improvement in the design and characterization of metal oxide gas sensors are essential [2-6]. Different types of ionization gas sensor and comparing to their absorption-type counterparts described in different research articles [7–10]. Some novel attempts of incorporation of low dimensional materials into the conventional capacity-type of electrode system has been reported, including the film of multiwall CNTS (MWCNTs) [11–14]. Some challenging sensing application with the help of a mobile robot carrying sensors on board are more flexible and practical for field applications like environmental exploration [15], gas distribution modelling [16], buried land mine detection [17] or pollution monitoring [18] etc. sensing devices with high sensitivity, stability, and rapid response [19–21] have also been demonstrated. By increasing surface volume ratio different types of sensing technique has also been introduced. metal-oxide nanostructures such as nanowires [22–29] and nanobelts [30–32] have been widely proposed in numerous studies.

Explosions are a phenomenon of underground coal mining and they may be either due to Methane (firedamp) alone or coal dust alone or both fire damp and coal dust. An early detection and alarm system for the presence of methane and CO gas in the underground coal mining environment will thus go a long way for ensuring the safety and security of the coal mines. Low power consumption is a fundamental requirement for a sensor system with an acceptable battery lifetime. Conventional metal oxide gas sensors, which are commonly used for sensing inflammable gases ((like CH_4) and other toxic gases (like CO)) suffer from relatively high temperature (>=300oC) leading to high power consumption (e.g. pellistors require 350-850mW and Taguchi gas sensors require 230-760mW). However, the application of silicon MEMS technology may permit the desired benefits of reduced thermal mass, miniaturization, low power, reproducibility and low unit-cost. In this study the fabrication of simple MEMS based gas sensor has been demonstrated.

Fabrication of Gassensor

In this fabrication a double sided polished wafer is taken for making the MEMS based gas sensor. The wafer thickness is 0.25mm and resistivity is 4 to 7 Ω-cm. After Standard cleaning I and standard cleaning II is done to remove un wanted silicon particles, wax, and inorganic particles. 0.8 to 1 micrometer oxide layer is deposited as a passivation layer. Three level photolithography done to make the complete device structure. After 1st level photolithography titanium and platinum deposited using sputtering technique. Gold electroplating is done on the top of the micro heater elements, inter digited electrode (IDE) and contact pads.

Etch-back of gold from microheater element and IDE is done by using 2nd level lithography and 3rd level photolithography is done backside alignment for patterning of silicon dioxide for formation of membrane and scribe lines. The most important part is the micromachining technique. The

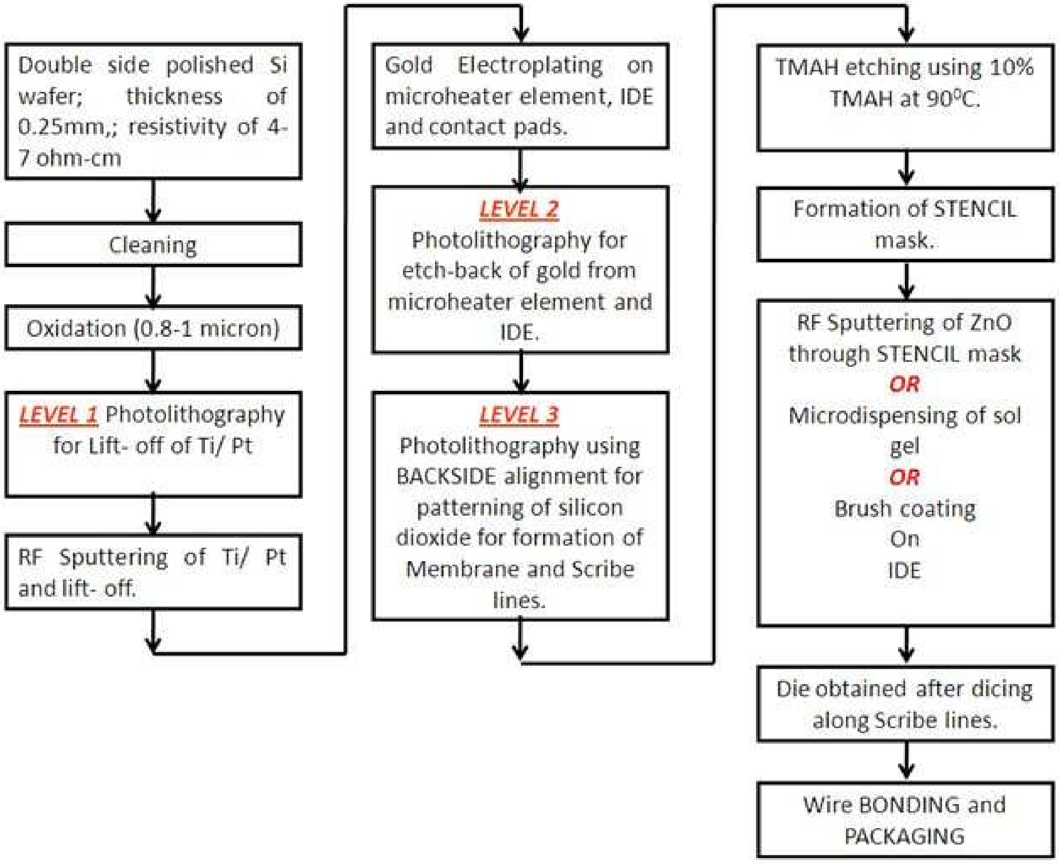

Figure 1: Process flow chart of entire 2" process for obtaining 3mm X 3mm die of microheater

power consumption can be controlled in silicon technique by the different micromachining structure. From the back side of the device 2.4 mm X 2.4 mm silicon substrate is extracted by using standard TMAH solution. Here a 100 micrometer silicon substrate is left from the bottom of the heater element. The better batter performance low power consumption can be done if the full silicon substrate can be removed from the bottom of heater where the heater element will be float on the top of the silicon di-oxide material. Titanium and platinum composite is used for making the better heating substrate by which absorbed gases are reduced. The power consumption factor is depends on the other phenomena is that the size of the die. If the die size reduces then the device operating voltage reduces which will be help full for coal mine.

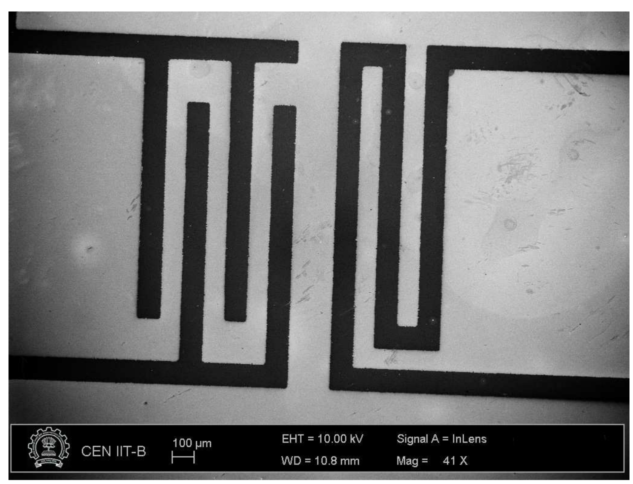

Figure 2: FESEM image of fabricated IDE and microheater

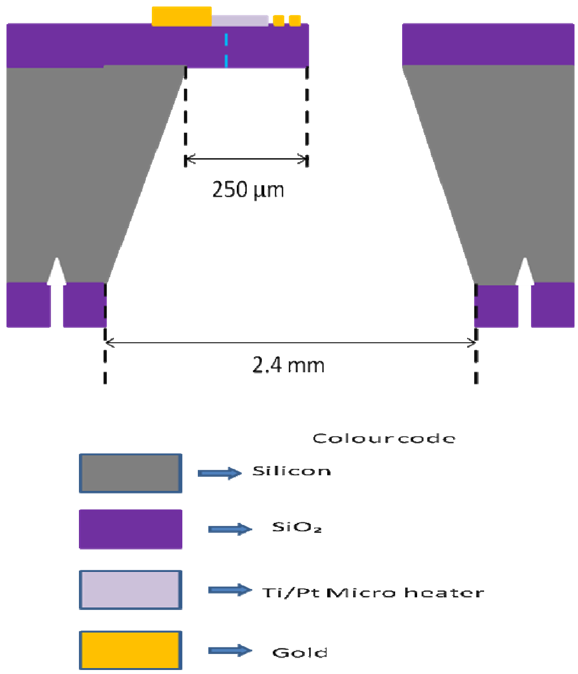

Figure 3: Micromachined structure from the back of the device

Analytical Discussion

Zinc oxide is deposited on the top of the IDE as the sensing material. Sensitization and activation is the other important part for getting better sensing response. It can be deposited the sensing material by using different deposition technique. Here sputtering of ZnO is done for sensing material which is shown in figure 4.

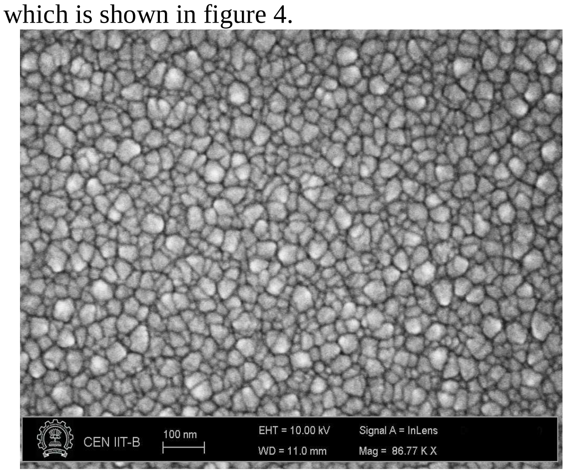

Figure 4: FESEM image of deposited ZnO

The heater power consumption of the fabricated device is less than 150 mW as the operating voltage is 6V. Due to low power consumption the device can be used for detecting the toxic gases in the deep level of coal mine. Table I shows the specification of the microheater.

TABLE I
SPECIFICATIONS OF THE MICROHEATER

Sl No.	Specifications of the device	
	Specifications	**Value**
1	Power consumption	<=150mW
2	Operating voltage	6V
3	Microheater filament	Titanium, Platinum
4	Operating temperature	220^{o}C
5	Sensor Electrode	Coplanar IDE

From the fabricated microheater different types of phenomena is observed. First of all the stability of the deposited titanium and platinum is observed and different types of ratio of Ti/Pt are chosen and optimized. The other important part is resistance of deposited Ti/Pt by which the high temperature can be achieved. The characterization of microheater is done by using proxima and the heater resistance is measured around 130 to 150Ω which is good for high temperature (<=150^{o}C) and low power consumption.

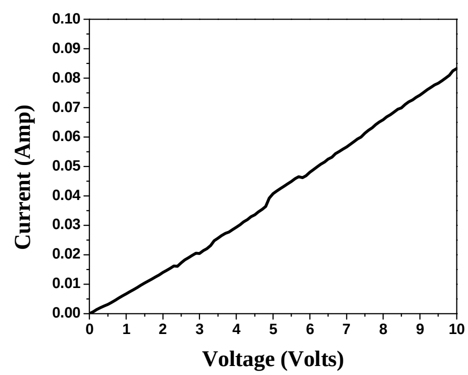

Figure 5: Characterization of microheater (I-V)

Different types of sensing layer can be fabricated here the nano structure is used for making the sensing layer. As the surface to volume ratio is high for nano structure it shows the better result.

TABLE II
Specifications of the Sensing layer

Sl No.	Identity	Specifications
1	Low temperature response	Nano structures
2	Gas sensing material (using sputtering/ Sol-gel)	ZnO
3	Reduction of operating temperature	<=200^{o}C

Conclusion

Micro electro mechanical based gas sensor is well established technique for getting low power consumption. Here the MEMS structure is used and ZnO sensing material is also fabricated. The characteristics of ZnO nanoparticle sensors under various operation temperatures were examined. The optimized operating temperature was 120 °C with the proposed ZnO nanowire designed.

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References

[1] P.Bhattacharyya,S.Sen,A.Chatterjee, S.Das, K.Basu, A.Pal and H.Saha " MEMS based nanocrystalline metal oxide gas sensors for coalmine environment" International conference on MEMS and Semiconductor Nanotechnology, December 20-22,2005,IIT Kharagpur,India

[2] Physical chemistry of surfaces by A.W.Adamson & A.P.Gast , Page No. 271 6th edition

[3] Simon I., Barsan N., Bauer M., Weimer U, "Micromachined metal oxide sensors: opportunities to improve sensor performance", Sensors and Actuators, B73, ELSEVIER, 9-12

[4] Hille P., Strack H.,"A heated membrane for a capacitive gas sensor", Sensors and Actuators,A32 (1992) 321-325

[5] Astie S., Gue A., Schield E., Lescouzeres L, Cassagnes A., "Optimization of an integrated SnO2 gas sensor using FEM simulator," Sens. Actuators, A69 (1998) pp. 205-211

[6] Mandayo G.G., Castano ., "Carbon monoxide detector fabricated on the basis of a Tin oxide novel doping method", IEEE Sensors Journal Vol 2 No 4 Aug 2002 pp.326

[7] J. Suehle, R.E. Cavicchi, M. Gaitan, S. Semancik, Tin oxide gas sensor fabricated using CMOS micro-hotplates and in situ processing, IEEE Electron Device Lett. 24 (1993) 118–120.

[8] G. Mueller, A. Friedberger, P. Kreisl, S. Ahlers, O. Schulz, T. Becker, A MEMStoolkit for metal-oxide-based gas sensing systems, Thin Solid Films 436 (2003) 34–45.

[9] P. Collins, K. Bradley, M. Ishigami, A. Zettl, Extreme oxygen sensitivity of electronic properties of carbon nanotubes, Science 287 (2000) 1801–1804.

[10] J. Kong, N.R. Franklin, C. Zhou, M.G. Chapline, S. Peng, K. Cho, H. Nanotube molecular wires as chemical sensors, Science 287 (2000) 622–625.

[11] A. Modi, N. Koratkar, E. Lass, B. Wei, P.M. Ajayan, Miniaturized gas ionization sensors using carbon nanotubes, Nature 424 (2003) 171–174.

[12] A. Modi, N. Koratkar, P. Ajayan, Carbon nanotube electrode films for gas sensing, 45th AIAA ASME ASCE AHS Struct., Struct. Dyn. and Mater. Conf. Palm Springs, American Institute of Aeronautics and Astronautics, CA, USA, 2004.

[13] Y. Zhang, J. Liu, X. Li, X. Tang, C. Zhu, Study of improving identification accuracy of carbon nanotube film cathode gas sensor, Sens. Actuators A: Phys. 125 (2005) 15–24.

[14] X. Li, J.H. Liu, Y. Zhang, J.Y. Dou,W.H. Liu, Y.N. He, C.C. Zhu, Study of catalyst grains effect on electrode of self-sustaining discharge carbon nanotubes gas sensor array, in: Vacuum Microelectronics Conference, Davis, CA, USA, IEEE, 2001.

[15] Trincavelli, M.; Coradeschi, S.; Loutfi, A. Online Classification of Gases for Environmental Exploration. In Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), St. Louis, MO, USA, 11–15 October 2009; pp. 3311–3316.

[16] Lilienthal, A.J.; Reggente, M.; Trincavelli, M.; Blanco, J.L.; Gonzalez, J. A Statistical Approach to Gas Distribution Modelling

with Mobile Robots The Kernel DM+V Algorithm. In Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), St. Louis, MO, USA, 11–15 October 2009; pp. 570–576.

[17] Rachkov, M.; Marques, L.; De Almeida, A. Multisensor demining robot. Autono. Robots 2005, 18, 275–291.

[18] Trincavelli, M.; Reggente, M.; Coradeschi, S.; Ishida, H.; Loutfi, A.; Lilienthal, A.J. Towards environmental monitoring with mobile robots. In Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Nice, France, 22–26 September 2008; pp. 2210–2215.

[19] 1. Khun, K.K.; Mahajan, A.; Bedi, R.K. Contact effects and extraction of intrinsic parameters in poly (3-alkylthiophene) thin film field-effect transistors. *J. Appl. Phys.* **2009**, *106*, 124509:1–124509:7.

[20] Wongwiriyapan, W.; Inoue, S.; Okabayashi, Y.; Ito, T.; Shimazaki, R.; Maekawa, T.; Suzuki, K.; Ishikawa, H.; Honda, S.; Mori, H.; *et al*. Highly stable and sensitive gas sensor based on single-walled carbon nanotubes protected by metal-oxide coating layer. *Appl. Phys. Express* **2009**, *2*, 095008–095010.

[21] Arafat, M.M.; Dinan, B.; Akbar, A.S.; Haseeb, M.A. Gas sensors based on one dimensional nanostructured metal-oxides: a review. *Sensors* **2012**, *12*, 7207–7258.

[22] 6. Fan, Z.; Wang, D.; Chang, P.-C.; Tseng, W.-Y.; Lu, J.-G. ZnO nanowire field-effect transistor and oxygen sensing property. *Appl. Phys. Lett.* **2004**, *85*, 5923–5925.

[23] Sysoev, V.V.; Button, B.K.; Wepsiec, K.; Dmitriev, S.; Kolmakov, A. Toward the nanoscopic “electronic nose”: Hydrogen *vs.* carbon monoxide discrimination with an array of individual metal oxide nano- and mesowire sensors. *Nano Lett.* **2006**, *6*, 1584–1588.

[24] Li, C.; Zhang, D.; Han, S.; Liu, X.; Zhou, C. Surface treatment and doping dependence of Tn2O3 nanowires as ammonia sensors. *J. Phys. Chem. B* **2003**, *107*, 12451–12455.

[25] Qi, P.; Vermesh, O.; Grecu, M.; Javey, A.; Wang, Q.; Dai, H. Toward large arrays of multiplex functionalized carbon nanotube sensors for highly sensitive and selective molecular detection. *Nano Lett.* **2003**, *3*, 347–351.

[26] Li, J.; Lu, Y.; Cinke, M.; Han, J.; Meyyappan, M. Carbon nanotube sensors for gas and organic vapor detection. *Nano Lett.* **2003**, *3*, 929–933.

[27] Zhai, J.; Wang, L.; Wang, D.; Li, H.; Zhang, Y.; He, D.; Xie, T. Enhancement of gas sensing properties of CdS nanowire/ZnO nanosphere composite materials at room temperature by visible-light activation. *ACS Appl. Mater. Interfaces* **2011**, *3*, 2253–2258.

[28] Francioso, L.; Taurino, A.M.; Forleo, A.; Siciliano, P. TiO2 nanowires array fabrication and gas sensing properties. *Sens. Actuators B Chem.* **2008**, *130*, 70–76.

[29] Hu, P.; Du, G.; Zhou, W.; Cui, J.; Lin, J.; Liu, H.; Liu, D.; Wang, J.; Chen, S. Enhancement of ethanol vapor sensing of TiO2 nanobelts by surface engineering. *ACS Appl. Mater. Interfaces* **2010**, *2*, 3263–3269.

[30] Comini, E.; Faglia, G.; Sberveglieri, G.; Pan, Z.; Wang, Z.L. Stable and highly sensitive gas sensors based on semiconducting oxide nanobelts. *Appl. Phys. Lett.* **2002**, *81*, 1869–1871.

[31] Chen, Y.; Zhu, C.; Cao, M.; Wang, T. Photoresponse of SnO2 nanobelts in situ grown on interdigital electrodes. *Nanotechnology* **2007**, *18*, 285502:1–285502:5.

[32] Qian, L.H.; Wang, K.; Li, Y.; Fang, H.T.; Lu, Q.H.; Ma, X.L. CO sensor based on Au-decorated SnO2 nanobelt. *Mater. Chem. Phys.* **2006**, *100*, 82–84.