TEMPERATURE-CONTROLLED, MICROMACHINED ARRAYS FOR CHEMICAL SENSOR FABRICATION AND OPERATION

TECHNICAL FIELD

The present invention relates to temperature-controlled sensors and processes for making and using the same. More particularly, the present invention relates to temperature controlled chemical sensors which are made by micromachining techniques and method of using the same.

BACKGROUND ART

Various types of solid state gas sensors have been in use for decades for applications where their performance is deemed adequate for a given task as reported by Yamazoe et al (N. Yamazoe and T. Seiyama, Proc. of the 3rd Int'l. Conf. on Solid State Sensors and Actuators (IEEE, Philadelphia, 1985) p. 376). Examples of such gas sensors include devices that detect unsafe levels of poisonous or explosive gases in work environments as well as sensors that measure humidity or contaminants within process gas streams. However, performance problems , particularly those related to poor stability, slow response time and interference effects from constituents other than those being measured, have been known to severely limit the utility of chemical sensors (P. T. Moseley and B. C. Tofield, Solid State Gas Sensors (Adam Hilger, Bristol, 1987)). A similar scenario exists for sensors that are used for composition and concentration measurements in solutions.

While sensors operate on a variety of principles, they all depend on the occurrence of chemical interaction between the probed environment and the active portion of the sensor to produce a sensor signal that can be interpreted to provide specie(s) concentration(s). A certain, but limited level of selectivity can be introduced in sensors by altering the type of active material employed as reported by Morrison (S.R. Morrison, Proc. of the 2nd Int'l. Meeting on Chemical Sensors (Bordeaux, 1986), page 39). It is also recognized that temperature changes can affect the solid state devices by altering interaction kinetics and other properties (J.F. McAleer, P.T. Moseley, J.O.W. Norris and D.E. Williams, J. Chem. Soc. Faraday Trans. I 83, 1323 (1987)).

In many cases, single active sensing elements are applied, but the literature has been increasingly reporting results from developmental work on integrated element array devices which produce multiple outputs that are analyzed by known pattern recognition techniques.

Various structures have been micromachined for use in sensing. Ikegami and Kaneyasu describe an integrated sensor array of 6 elements that uses pattern recognition techniques to identify gases such as ammonia, menthol, and hydrogen sulfide (A. Ikegami and M. Kaneyasu, 1985 Digest of Technical Papers, Int. Conf. Solid State Sensors and Actuators, 'Transducers 85' IEEE (Library of Congress 84-62799) p. 74). The array is fabricated on alumina, and is not adaptable to the use of Si micromachining techniques. The heater for the sensor array is a single large structure which is applied to all the elements simultaneously. Therefore, the elements can not be individually temperature controlled.

Chang et al (S.C. Chang and D.B. Hicks, 1985 Digest of Technical Papers, Int. Conf. Solid State Sensors and

Actuators, 'Transducers 85' IEEE (Library of Congress 84-62799) p. 381) describe an integrated sensor with an integrated heater element fabricated using Si integrated circuit thin film techniques. This sensor does not, however, have good thermal isolation from the rest of the chip. Because of this, it does not respond rapidly to temperature changes and requires a substantial amount of power to operate. In addition, this device does not include a separate layer for temperature measurement and heat dispersal. Therefore, temperature measurements which are effected by monitoring the heater resistance are not accurate.

Wang et al (X. Wang, S. Yee, and P. Carey, Proc. of the 1992 IEEE Workshop on Sensors (Hilton Head, 1992) p. 23) describe an array of sensor elements fabricated on Si membranes produced by micromachining technology. The technique used to create the sensor, however, requires aligning an etch of the back side of a Si wafer with sensor structures on the front side. This requires special photolithography techniques, which are not compatible with the processes available at commercial foundries and is therefore is more expensive to set up. There is no separate temperature sensing layer provided in the device of Wang et al. Moreover, the fabrication methods described do not include the possibility of using the integrated heater to process the sensing materials grown above it. Finally, no consideration is given to novel temperature programming techniques to enhance response.

Najafi et al (N. Najafi, K.D. Wise, R. Merchant and J.W. Schwank, Proc. of the 1992 IEEE Workshop on Sensors (Hilton Head, 1992), p. 19) describe an integrated multi-element gas analyzer created by micromachining technology using an integrated heater, silicon resistor temperature sensors, and sensing film with four contacts. The fabrication technique used here also involves a backside etch of the Si wafer, with the equipment expense problems and alignment difficulties associated with the topside sensing elements. The temperature measurement is done using resistors which are interdigitated with the heaters, and so may give higher temperatures than are at the actual sensing surface. Again, the fabrication methods described do not include the possibility of using the integrated heater to process the sensing materials grown above it. Although temperature ramps are used as a part of a sensing process, there is no mention of the use of very rapid, i.e., from 1 msec to 1 sec, temperature pulses to enhance sensing response and device performance.

The present invention uses both chemically-tuned elements and temperature variation to achieve superior sensing performance, especially with respect to analyzing mixtures. During the course of the present invention, new technology was developed which combines the previously-recognized materials and temperature concepts with a unique micromachined hotplate array design in order to realize a commercially-viable miniature sensor for analyses of species mixtures.

DISCLOSURE OF THE INVENTION

It is accordingly one object of the present invention to provide a temperature controlled sensor element.

Another object of the present invention is to provide a temperature controlled sensor which includes an array of individually controlled sensor elements.

A further object of the present invention is to provide a temperature controlled sensor which includes an