Design of high concentration oxygen sensor based on MEMS chip

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Abstract. There are increasingly urgent needs for low power, high performance, and low cost oxygen sensor in oxygen concentrator industry. A new type of MEMS oxygen sensor based on MEMS thin film resistor and heat transduction is designed. Using clean room technology processing micron-size chip, help reduce post-production costs. Preliminary experiment results demonstrate that the output voltage signal is proportional to the oxygen concentration in normal working range, and the detection accuracy can reach less than 1%.

Keywords: oxygen sensors, MEMS, thin-film resistors, low power consumption, high oxygen concentration.

1. Introduction

With the development of social economy, more and more people attach importance to health care; home oxygen concentrator market is also growing. General household use of oxygen equipment is to improve the use of molecular sieve oxygen concentration, to relieve fatigue, to increase metabolism, and to improve human health functions. Only suitable concentration of oxygen can achieve health function, and therefore the device needs to monitor the output oxygen concentration. According to the national standard of oxygen machine industry "YY0732-2009 medical oxygen concentrators safety requirements" [1], when the oxygen concentration is less than 50%, the system need to lit red light alarm; when the oxygen concentration is higher than 82%, the system need to lit green light, marking system is working properly; and when the oxygen concentration is between 50-82%, the system need to lit yellow light. In the current detection method of gas concentration, there are many ways to detect the concentration of oxygen, but the most commonly used electrochemical method is for low oxygen concentration measurements. The sensor life expectancy is greatly shortened at high oxygen concentrations, and is not widely applied in oxygen concentrator.

2. High oxygen concentrations sensor

Currently, the main methods for high oxygen concentration detection are zirconia oxygen sensor and ultrasonic sensor. Zirconia oxygen sensor is mainly based on the ionic conduction of stable zirconia at high temperature [2]. Detection method is that through the guide tube, the measured gas is introduced into the zirconia detection chamber, and then through heating element the zirconia is heated to operating temperature (650 ℃ above), The concentration difference of oxygen gas and the reference gas cause a potential difference, whereby the oxygen concentration can be calculated. The advantage of this method is that is no influence of gas temperature and by using different guide tube, oxygen content can be detected at various gas temperatures. This flexibility is being used in many industrial online testing. The disadvantage is slow reaction time, complex structure, and easily affected detection accuracy.

Ultrasonic measurement principle is that in a fluid filled pipe, when ultrasonic pulse passes along the fluid, in the downstream direction and the reverse flow direction has different propagation time. When gas flow rate is different, upstream and downstream time difference is different, thus gas flow rate can be detected by the time difference. The concentration of detection is also using the same ultrasonic pulse, under the dual gas composition; the concentration ratio of the two components is different, ultrasonic pulse propagation velocities in the gas are also different. Now oxygen concentrator mainly use ultrasonic type oxygen concentration sensor. This method is simple in principle, but the price is more expensive, and need more complex single sensor calibration work, so the cost is difficult to drop, limits its application in industry

3. Oxygen detection based on MEMS chip

Semiconductor processing technology is used in MEMS chip fabrication processing, with mass-production capability and high repeatability, thus the price is low and, the stability and economy of oxygen sensors can be improved. For measuring oxygen concentration, thermal conductivity type oxygen sensors is designed based on gas thermal conductivity differences. This study adopts the suspended thin film resistor for heating and temperature measurement. Suspended thin film resistor can effectively reduce the heat loss caused by heat conduction, and guarantee the independence between the resistors. Its working principle is shown in Figure 1.

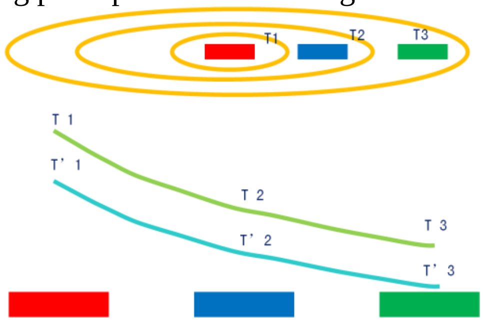

Fig. 1 Detection principle of oxygen concentration based on MEMS

In Figure 1, T1, T2 and T3 are suspended film platinum resistors, T1 works as the heater, emitting a constant heat to increase the flow air temperature. T2 and T3 work as temperature measurement devices. The measured gas flow into the gas chamber is heated to a high temperature in contact with the thermostat. When the gas flow, according to three basic ways of heat transfer: heat conduction, convection and radiation, the overall heat loss the overall heat loss as shown in equation one.

$$Q = Q_{convection} + Q_{conduction} + Q_{radiation} \quad (1)$$

Because of adopting suspended membrane resistor, its length to thickness ratio is 3000 or more, the heat conduction can be neglected [3]. At a constant temperature mode, sensor surface thermal radiation also changes very little, without consideration. Therefore, the heat loss of the sensor can be expressed as:

$$Q_{convection} = \lambda m(T - T_0) \quad (2)$$

Wherein, λ is the thermal conductivity of the gas, T is the sensed temperature, T_0 is the ambient temperature, and m is the mass flow rate of the gas. The thermodynamic theory shows that if the gas to be measured only binary gas mixture, the thermal conductivity of a mixed gas component to be measured gas concentration is linear, i.e., C1 = (λ-λ0) / (λ1-λ0), thermal conductivity of oxygen and nitrogen is different, therefore, as long as the measured thermal conductivity of the mixed gas, wherein the oxygen concentration can be known. The different oxygen concentrations and flow rates of gas heat away different, by detecting the resistance value of T2 and T3 pre-calibrated values for comparison can be drawn information flow rate and oxygen concentration of the gas. In order to ensure the accuracy, relatively independent platinum resistor is designed to detect the ambient temperature on the chip to be amended.

4. MEMS chip and testing

MEMS chip processing flow chart used in this study as shown in Figure 2. By (100) type silicon (a), first deposited multilayer films as a supporting structure (b), then by stripping fabrication resistance wire (c), followed by dry etching to open etching window (d), and then release the film by a wet etching process (e), and finally produced film resistor wire (f). From the point of manufacturing process, sensor processing process is simple and controllable, can guarantee a higher yield (4, 5).

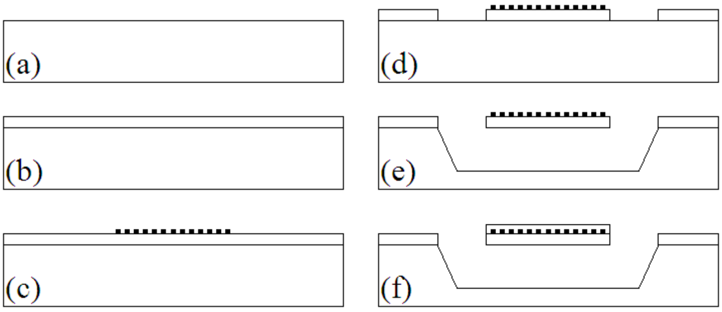

Fig.2 Fabrication process of thermal conductivity type oxygen sensor

(a) substrate silicon; (b) sedimentary supporting membrane; (c) production metal electrode; (d) etching corrosion window; (e) etching silicon substrate; (f) the sedimentary protective film.

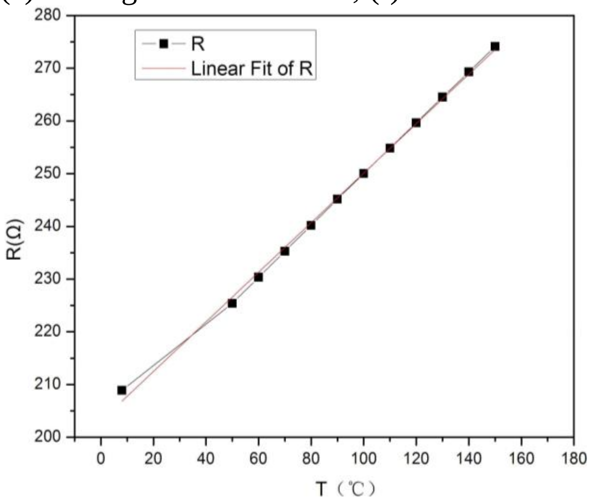

Fig. 3 Relation curve between resistance and temperature of thin film Pt resistor on chip

For the finished chip, we first calibrated the temperature coefficient of resistance of the actual device. Thin film platinum resistance versus temperature curve is shown in Figure 3, according to the measured resistance value and calculation, the thin film platinum resistance temperature coefficient of resistance is 0.0024/ ^{o}C. The completely packaged chips are tested using different ratios of oxygen and nitrogen gas mixture, with a constant current control circuit. The results are shown in Figure 4. We can see that the oxygen concentration and voltage has a good linear relationship. And when the oxygen concentration changed 1%, the output voltage changed at mV level, and the circuit detects the signal up to the microvolt level, therefore, the actual detection accuracy up to 1% or less can be achieved.

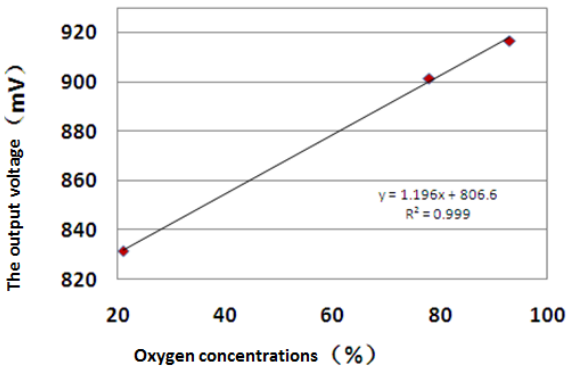

Fig. 4 Relation curve between oxygen concentration and output voltage

5. Conclusion

Oxygen sensor in automotive electronics, medical electronics and other industries has a wide range of applications. From the oxygen sensor oxygen as a starting point, MEMS chip is designed based on the thermal conductivity of the oxygen sensor principle. The finished chip was verified through preliminary experiments, the output signal is proportional to the concentration of oxygen, detecting oxygen concentration of about 1% accuracy. Using this chip can reduce the system cost and power consumption of oxygen sensors, increasing the efficiency and service life, meet the needs of accurate monitoring used in the medical oxygen concentrator and can be extended to other applications and industries.

Acknowledgements:

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References

[1] Oxygen industry national standard: "YY0732-2009 medical oxygen concentrators' safety requirements"

[2] TaoFeng, etc. Development zirconia substrate type NOx gas sensor, the sensor in the world, Vol. 6, 2014

[3] Binxian Du etc, Thermal conductivity gas sensor principle and work to improve the detection, chemical engineering and equipment, Vol. 2, 2010

[4] Lei Xu, Zhengfei Dai, Tie Li, et al., "IC Compatible Fusion of Micromachined Hotplatform and Nanostructured Porous Film for High-Performance Gas Sensors," *Transducers 2013*, Barcelona, Spain, June 16-20 2013 (Poster)

[5] Lei Xu, Tie Li, Rui Zheng, et al., "A Low Power Catalytic Combustion Gas Sensor Based on a Suspended Membrane Microhotplate," *IEEE NEMS 2011*, Kaohsiung, Taiwan, February 20-23,2011 (Oral)