Methane Sensor for Cordless Utility Gas Alarms

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ABSTRACT

There is a strong desire for utility gas alarms to be made cordless by battery operation. For this reason, the power consumption for methane sensors must be made 1/1,000th or lower than that of current products. Osaka Gas and Fuji Electric have achieved a sensor with this ultra low power consumption by attempting to create a thin membrane and miniaturizing the sensor using MEMS (Micro Electro Mechanical Systems) technology to drive the sensor intermittently to generate heat only at the instant of detection. Currently we are participating in the "Technological Development for a Next-generation Highly-reliable Gas Sensor" project, a New Energy and Industrial Technology Development Organization (NEDO) grant project, and the long-term reliability of the sensor is being verified by large-scale field tests.

1. Introduction

At present, utility gas alarms for home use can be found in approximately 40% of households, but the penetration rate for this market has remained essentially unchanged since 1999. Factors inhibiting greater market penetration include the 100 V AC power specification of existing utility gas alarms and the restriction that the alarms be installed at high locations in a kitchen. Consequently, cordless, battery-powered utility gas alarms are strongly desired. However, because methane sensors must be made to consume very low power that is less than 1/1,000th the power consumption of existing products, the technical challenges for long-term battery power have been extremely high and such technology has been a dream.

Since 1980, Fuji Electric has continued to develop and sell utility gas alarms, and has developed sensors based on semiconductor designs and manufacturing technology that utilizes micro electro mechanical systems (MEMS) technology. This paper introduces a MEMS methane sensor, jointly developed with Osaka Gas Co., that realizes cordless operation in a utility gas alarm.

2. Background

2.1 Prior technology

Semiconductor type gas sensors utilizing tin oxide (SnO_2) as gas sensitive material have been widely used as methane sensors in utility gas alarms. Fig. 1 shows the detection mechanism of this semiconductor type gas sensor. SnO_2 is an n-type semiconductor with electrons as the majority carriers. In a clean air environment, the resistance value increases due to the chemisorption of oxygen, but if a flammable gas such as methane (CH_4) is present, the chemisorbed oxygen reacts with the gas to increase the carrier concentration in the SnO_2 and reduce the electrical resistance. In the case of methane, however, which has low reactivity among flammable gases, the sensor element must be heated to about 400 °C.

Conventional methane sensors, commonly called "sintered body type sensors" or "bulk type sensors" are the mainstream. These sensors, in which gas-sensitive materials consisting mainly of SnO_2 surrounding a metal heater coil are sintered, have reached their limit for reducing power consumption through miniaturization.

2.2 Requirements for cordless utility gas alarms

So that utility gas alarms can be powered by batteries at a realistic cost for the duration of their 5-year lifecycles, the average power consumption of the methane sensor part must be reduced to 0.1 mW or less. (Here, the average power consumption refers to the power consumed to drive the sensor elements and the control circuit.) This reduction in power consumption is

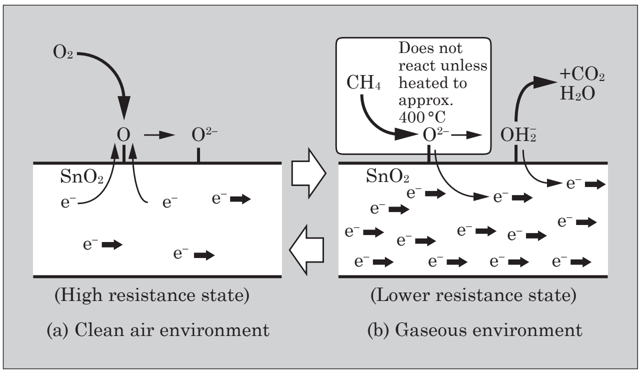

Fig.1 Sensing mechanism of semiconductor gas sensor

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a novel concept and is 1/1,000th that of existing methane sensors.

While working to realize such ultra low power consumption, basic performance that satisfies the “utility gas alarm inspection regulations” (JIA E001-07) of the Japan Gas Appliances Inspection Association and 5-year long-term reliability are sought.

3. Development of Methane Sensor Having Ultra Low-Power Consumption

3.1 Thinner film gas sensor

Osaka Gas Co. has been researching thin film gas sensors since 1980, and by employing a thin film fabrication technique known as “RF sputtering” and controlling microstructures at the nanometer level, has developed a method for producing SnO_2 thin film having a special “nano columnar structure.” Fig. 2 shows a scanning electron microscope (SEM) photograph of this structure. Because gas molecules are able to diffuse between the columnar structures, a high sensitivity is realized and the thin film has the features of stable crystalline particles and sensitivity that remains unchanged over long periods of time.

Osaka Gas has also developed a “thin film methane sensor” having high sensitivity and selectivity to methane by laminating, on top of a columnar-structure SnO_2 thin film, a catalytic thick film through which the combustion-removal of flammable gases such as hydrogen (H_2), carbon monoxide (CO), alcohol and the like is possible.[1]

3.2 Ultra low power consumption by applying MEMS technology

Osaka Gas Co. and Fuji Electric have jointly developed a thin film micro methane sensor based on Osaka Gas’s thin film sensor technology and using Fuji Electric’s proprietary MEMS technology[2].

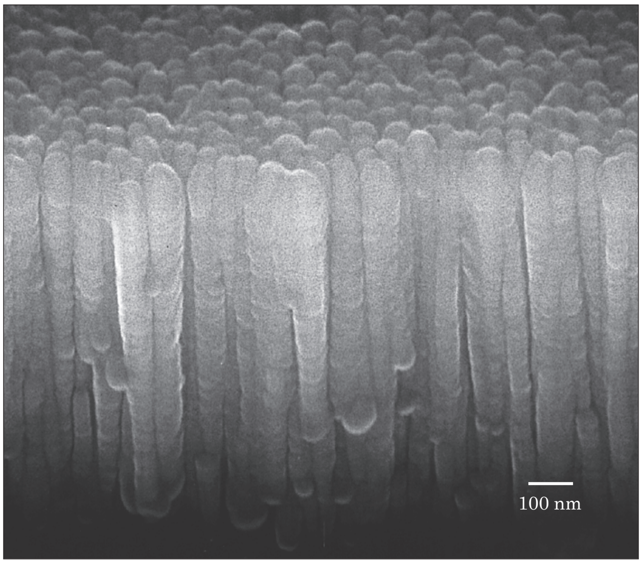

Fig.2 SnO_2 thin film SEM photograph

As shown in Fig. 3, the sensor is constructed with a new structure consisting of a thin film heater, SnO_2 thin film and catalytic thick film formed on top of a thin film diaphragm, and the sensor is intermittently driven and heated only at the time of detection.

Features of ultra low power consumption are as follows.

(1) Spot heating

By forming a thin film heater on a thin film diaphragm having a thickness of several microns, small areas of several hundreds of microns in size, and tending to retain their heat, can be heated.

(2) Short pulse heating

Because SnO_2 thin film, which has a small heat capacity, is formed above a thin film heater, with an electrically insulating layer positioned in between, the thermal responsiveness is good and short pulse heating can be implemented.

(3) Intermittent driving

With the ability to perform short pulse heating, intermittent driving is possible such that heating is performed only at the moment of detection and is stopped at all other times.

Figure 4(a) shows the heater power consumption and Fig. 4(b) shows the gas responsiveness of the newly developed thin film micro-methane sensor. Fig. 4(a) shows the relationship between heater power consumption and surface temperature (center part) at a steady state, and Fig. 4(b) shows the relationship between heater heating time and sensor resistance value when 30 mW of power is supplied to the heater. From these drawings, it can be seen that the heater power

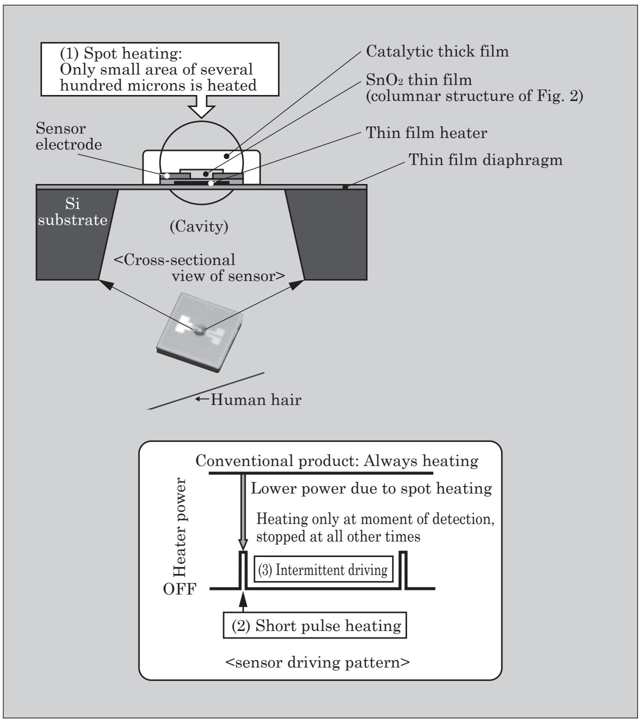

Fig.3 Structure and driving patter of thin film micro methane sensor

necessary for heating the sensor to 400 °C is less than 30 mW, which is low, and that the sensor responds quickly to gas, with methane sensitivity (the change in the sensor resistance value in air) occurring in several tens of milliseconds. Thus, by reducing the power consumed in heating the sensor to 400 °C and enabling short pulse driving by improving gas responsiveness, an average power consumption that is 1/1000th that of existing methane sensors was realized.

Note that in Fig. 4 it can be seen that for a heater heating time of several tens of milliseconds, sensitivity to H_2 and CO is established (when the resistance value in gas is lower than the resistance value in air) but that the H_2 and CO sensitivity diminishes thereafter (with the resistance value in H_2 and CO increasing and approaching the value of resistance in air). This behavior occurs after several tens of milliseconds because H_2 and CO are combusted and removed through the catalytic thick film, and the concentration of gas reaching the SnO_2 surface diminishes.

3.3 Basic performance

A methane sensor for use in utility gas alarms must have high sensitivity to methane, which is a major component of town gas, and also must have selectivity with regard to interfering gases such as H_2 and CO.

Figure 5 shows the gas sensitivity characteristics of the new developed thin film micro methane sensor. Gas sensitivity is defined as the ratio (Rair/Rgas) of sensor resistance in a clean air environment (Rair) to the sensor resistance in a gaseous environment (Rgas).

From Fig. 5, it can be seen that gas sensitivity increases with respect to methane concentration, and that at the level of 2,000 ppm of methane, the sensitivity is greater than 5, while on the other hand, for H_2 and CO, gas sensitivity is suppressed to rather low levels compared to methane, and therefore the sensor does exhibit sufficient basic performance as a methane sensor for use in utility gas alarms.

4. Long Term Reliability

In addition to exhibiting the basic performance described above, a methane sensor for use in a utility gas alarm is also required to provide long-term reliability with at least a 5-year replacement term.

Fuji Electric is participating in the “Next Generation High Reliability Gas Sensor Technical Development (2008 – 2011)” project sponsored by the New Energy and Industrial Technology Development Organization (NEDO), and aims to establish long-term reliability. In this project, accelerated testing is performed in a laboratory based on large-scale field tests and the data thereof with the aim of realizing a useful service life of at least 5 years. In the large-scale field tests, so that data can be acquired in various types of installation environments, the following factors were considered broadly as conditions of the installation

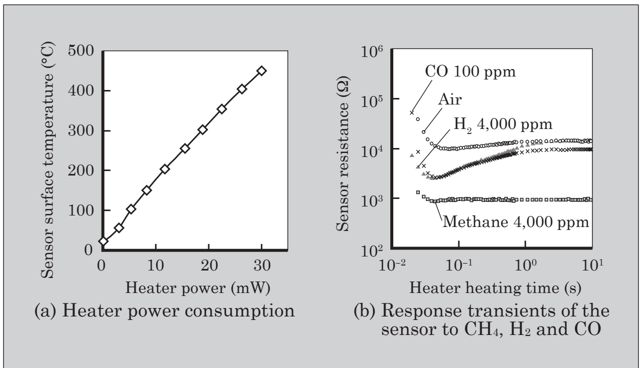

Fig.4 Heater power consumption and gas responsiveness of thin film micro methane sensor (responsiveness of sensor resistance in various gas environments)

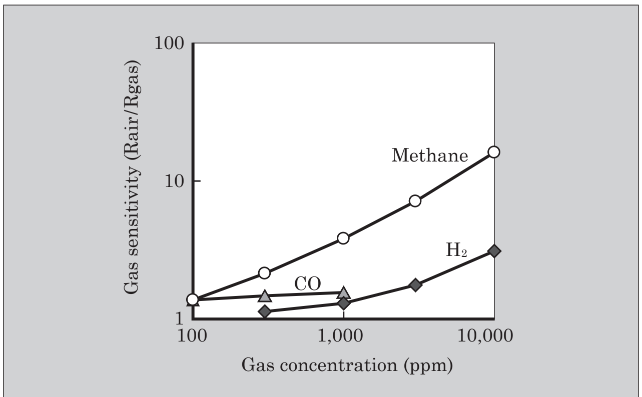

Fig.5 Gas sensitivity characteristics of thin film micro methane sensor

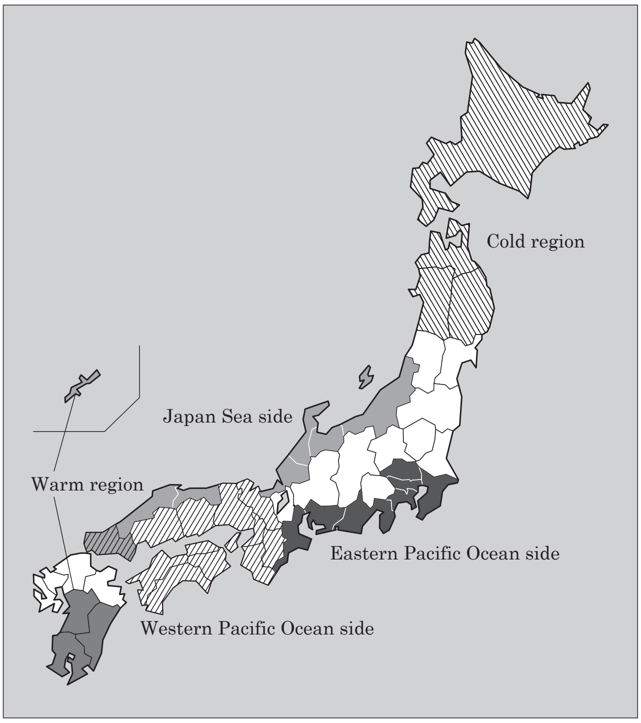

Fig.6 Installation sites of the large-scale field test

site: (1) geographical region (climate), (2) house type, (3) family structure, and (4) year built (building and painting materials). Fig. 6 shows the installation areas of the large-scale field test.

For this large-scale field test, 400, 200 and 60 units were tested in years 2008, 2009 and 2010, respectively, and field data of up to 2.5 years can be acquired so far. Additionally, the construction work for accelerated testing based on the accumulated data is proceeding according to schedule, and by the end of the project, long-term reliability corresponding to a service life of at least 5 years is anticipated.

(a) Existing product (AC power specification)
(b) Cordless product (Battery powered)

Fig.7 Appearance of utility gas alarms

5. Application to Utility Gas Alarms

Simultaneous with the development of methane sensors, cordless utility gas alarms that are equipped with such sensors are being studied.

Figure 7 shows the external appearances of existing and cordless utility gas alarms. The cordless product has the same footprint as the existing product, but with a thinner and simple profile. The cordless type utility gas alarm also has the same basic specifications as the existing product, and functions to detect gas leaks, incomplete combustion and fire.

6. Postscript

This paper has introduced a methane sensor for use in cordless utility gas alarms that incorporate MEMS technology, which is an area of expertise of Fuji Electric.

By realizing the early mass production of this sensor and making efforts to popularize utility gas detectors for residential use, Fuji Electric intends to contribute to the safe use of energy.

Some of the research herein was carried out with support from the “Next Generation High Reliability Gas Sensor Technical Development” project of the New Energy and Industrial Technology Development Organization (NEDO) and by collaborative development with the Osaka Gas Co. The authors wish to express their gratitude to all parties concerned.

References

(1) Ohnishi, H. et al. High Sensitive Methane Sensor, Procedure of 19th World Gas Conference-Milan, IGU/E7-94 (1994) 1-15.

(2) Suzuki, T. et al. Sensors and Actuators B: Chemical. 2005, vol.109, p.185-189.