M-3-01 (Invited)
Extended Abstracts of the 2019 International Conference on Solid State Devices and Materials, Nagoya, 2019, pp513-514

Integrated Hybrid MEMS Hydrogen Sensor with high sensitivity and wide dynamic range

Hiroaki Yamazaki[1], Yumi Hayashi[1], Kei Masunishi[1], Tomohiro Saito[1], Daiki Ono[1], Naofumi Nakamura[1] and Akihiro Kojima[1]

[1] Corporate Research and Development Center, Toshiba Corporation
Komukai-Toshiba-Cho, Saiwai-ku
Kawasaki 212-8583, Japan
Phone: +81-44-549-2854 E-mail: hiroaki.yamazaki@toshiba.co.jp

Abstract

Hydrogen sensors have great potential for many applications. We present an integrated hybrid MEMS hydrogen sensor with high sensitivity of 5 ppm, wide dynamic range of 6 digits, and excellent hydrogen selectivity. The sensor consists of a micro-machined capacitive sensor with Pd-based metallic glass and a micro-thermal conductivity detector, are integrated on a single Si chip. The capacitive type shows high sensitivity of 5 ppm and excellent hydrogen selectivity, while the micro thermal conductivity-type has excellent linearity for high concentrations near 100 vol%. Our integrated sensor can therefore be used in many hydrogen-related applications.

1. Introduction

Hydrogen is utilized in diverse fields including energy, chemical industry as well as generated in nature and living body. Hydrogen sensors may therefore become widely used in many applications. Sensors are generally used for leakage detection [1] and process control [2], but they can also be applied to other areas, such as battery safety [3] and health care [4]. Table I shows hydrogen concentration specifications for various applications. These applications will require sensors with high sensitivity, wide dynamic range, excellent hydrogen selectivity, and low power consumption. In this paper, we present an integrated hybrid MEMS hydrogen sensor that can be used in such applications.

Table I Hydrogen concentration specifications

Applications	Hydrogen concentration
Leak detection [1]	1000 ppm – 10 vol%
Process control [2]	Several 10 vol% – 100 vol%
Battery safety [3]	Several vol%
Health care [4]	Several ppm – 100 ppm

2. Capacitive MEMS hydrogen sensor with Pd-based metallic glass

Many types of hydrogen sensors have been commercialized, including catalytic, semiconducting metal oxide, and thermal conductivity types. However, all of these sensors require heating for hydrogen sensing and thus power consumption is as high as several hundred mW to several W, making it difficult to realize low-power operation. We have thus proposed a capacitive MEMS hydrogen sensor using a Pd alloy as the sensing film [5]. Our sensor utilizes the change in capacitance that results from a change in the mechanical stress of the Pd alloy when it absorbs hydrogen. The Pd alloy does not require heat for hydrogen sensing. Moreover, this sensor device does not use any DC current owing to the structure of its capacitor. Our sensor thus realizes low-power operation. However, use of crystalline Pd results in slow response as well as hysteresis due to hydride formation. So for our Pd alloy, we thus focused on a Pd-based metallic glass, an amorphous alloy with promising characteristics for realizing fast response with no hysteresis. Figure 1 shows the hydrogen response characteristics of our first prototype sensors using the Pd-based metallic glass. The sensor using pure Pd had a very long response time, taking more than 2000 s to saturate. Furthermore, this sensor exhibited hysteresis when the hydrogen concentration was zero. In contrast, the sensor using the Pd-based metallic glass responded to hydrogen gas within several seconds, exhibiting a fast response.

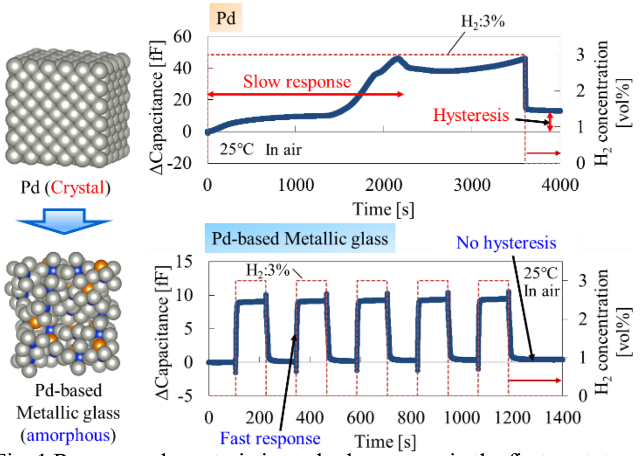

Fig. 1 Response characteristics to hydrogen gas in the first prototype sensors.

3. Single-chip integration of capacitive MEMS and micro thermal conduction detector

Concept

To realize high sensitivity and wide dynamic range, we present a hybrid MEMS hydrogen sensor that integrates a capacitive-type and thermal conductivity-type sensors on a Si substrate (Fig. 2) [6]. The capacitive-type sensor consists of an actuator on which a hydrogen-sensitive film is formed, a dielectric membrane in which a movable electrode is embedded, and a fixed electrode. The actuator and the membrane are connected by a spring structure. The actuator and the membrane are connected by a spring structure. Hydrogen can be detected with high sensitivity by adopting a spring structure that produces a large displacement amount. The thermal conductivity-type sensor has a structure in which a membrane including a micro-heater and a resistive-type temperature sensor is connected by an anchor via a spring with high thermal resistance. The thermal conductivity-type detects hydrogen according to the heat conduction difference of gas measured by a bridge circuit. The thin film structure provides low thermal capacitance and high thermal resistance and can realize rapid response and low-power consumption despite being of the thermal conductivity-type. The capacitive-type sensor detects hydrogen on the order of several ppm, and the thermal conductivity-type sensor detects hydrogen concentrations from several vol% to 100 vol%

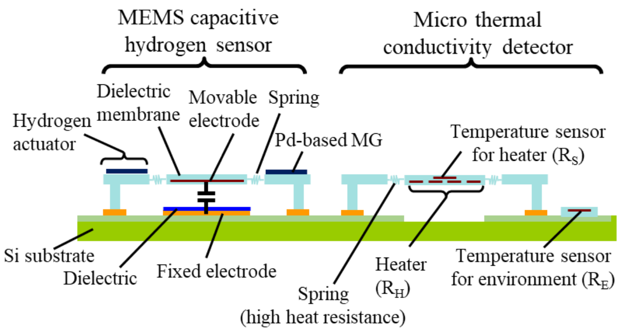

Fig. 2 Integrated hybrid MEMS hydrogen sensor

Measurement results and discussion

We fabricated the integrated hybrid sensor using a surface micro-machining process. Figure 3 shows the measured response curve for hydrogen gas in the fabricated hybrid sensor. Both sensors responded in several seconds with no hysteresis. The capacitive-type sensor showed high sensitivity in the low-concentration region, and the thermal conduction-type sensor showed high sensitivity in the high-concentration region (Fig. 4). We confirmed the capacitive-type sensor detected trace amounts of hydrogen from 5 ppm, and the thermal conductivity-type sensor showed high linearity in the high-concentration region. We evaluated interference with hydrogen gas (Fig. 5), and found that the capacitive-type sensor showed high selectivity, not responding to gasses other than hydrogen due to the properties of Pd. The thermal conductivity-type sensor responds to CH_4, CO_2, and He, but integration with the capacitive-type sensor can exclude the influence of other gases.

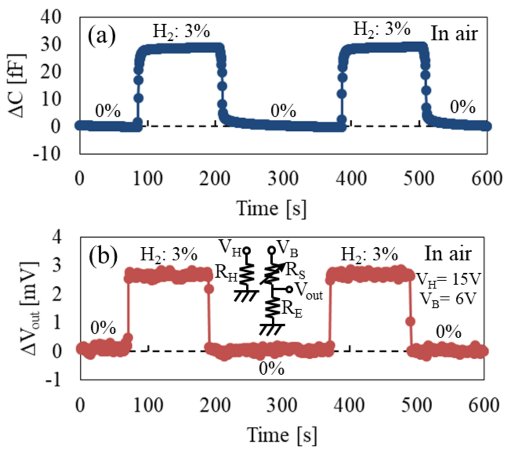

Fig. 3 Response characteristics to hydrogen gas of hybrid sensors (a) Capacitive-type (b) Thermal conductivity-type.

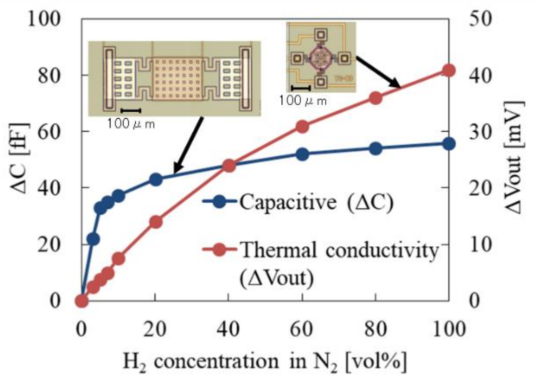

Fig. 4 Comparison of hydrogen concentration dependence on sensor output for the capacitive-type and the thermal conductivity-type.

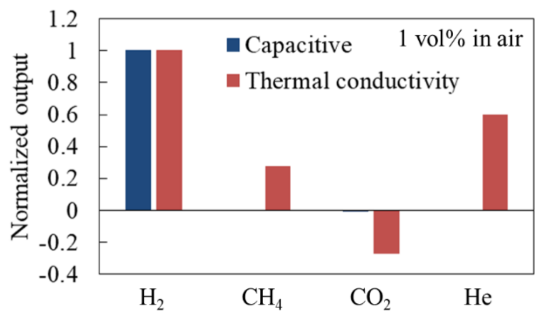

Fig. 5 Gas selectivity characteristics.

4. Conclusion

The proposed integrated hybrid MEMS hydrogen sensor achieves a high dynamic range from 5 ppm to 100 vol% by single-chip integration of capacitive and thermal conductivity hydrogen sensors with low-power consumption. The developed sensor exhibits fast response and excellent hydrogen selectivity. The proposed sensor is thus promising for various hydrogen-related applications.

References

[1] W. J. Buttner *et al.*, International Journal of Hydrogen Energy **3** (2011) 2462.
[2] T. Hübert *et al.*, *Sensors for Safety and Process Control in Hydrogen Technologies* (CRC Press, 2016).
[3] Storage Battery Systems, *SBS-H2 Hydrogen Gas Detector*, SBS-H2 datasheet.
[4] U. C. Ghoshal, Journal of Neurogastroenterology and Motility **3** (2011) 312.
[5] H. Yamazaki *et al.*, IEEJ Transactions on Sensors and Micromachines **7** (2018) 312.
[6] H. Yamazaki *et al.*, *Extended Abstracts of the 17th International Meeting on Chemical Sensors* (2018) 374.