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ANALYSIS OF HYDROGEN GAS DETECTION SENSORS

Annotation: *The hydrogen gas sensor plays an important role in ensuring the safety of various industries that are heavily dependent on high-pressure hydrogen gas. A new type of hydrogen sensors, solid electrolyte, metal oxide semiconductor and other types are described. The gas sensor for hydrogen has the characteristics of the target gas (chemically active, good thermal conductivity, low viscosity, etc.), so it is also a sensor with the most detection principle compared to other combustible gases. Therefore, there are many other sensors at the level of practical application or in development.Experiments are currently underway on high-pressure hydrogen gas leaks and large amounts of hydrogen gas leaks, and some of them are obvious to the general public. There are several methods for detecting hydrogen gas, but it is not possible to use the infrared method, which has made significant technological advances in recent years, because hydrogen is considered a monoatomic gas, unlike methane. There are three types of hydrogen sensors included in practical use for safety reasons: they are catalytic combustion, semiconductor type and gas thermal conductor type. There are several types of semiconductor sensors, but here we will analyze hot-wire semiconductor sensors. In particular, it is characteristic of a high reaction with a wide concentration range and the like.*

Key words: *hydrogen sensor, gas sensor, catalytic combustion, thermal wire semiconductor, DPP.*

Introduction

For the widespread distribution of hydrogen energy, including household fuel cells, it is necessary to ensure its safety, and gas sensors play an important role in this. In this scientific work, hydrogen gas sensors and relatively new sensors were analyzed. Hydrogen gases are very light compared to other combustible gases, and have a high probability of leakage. Ensuring safety is a prerequisite, so a hydrogen gas detection sensor is required. Methane is a compressed natural gas (CNG,20 mpa) and has applications in many industries. Of course, safety issues must be taken into account in practical application. Experiments are currently underway on high-pressure hydrogen gas leaks and large amounts of hydrogen gas leaks, and some of them are obvious to the general public [1]. There are several methods for detecting hydrogen gas, but it is not possible to use the infrared method, which has made significant technological advances in recent years, because hydrogen is considered a monoatomic gas, unlike methane. There are three types of hydrogen sensors included in practical use for safety reasons: they are catalytic combustion, semiconductor type and gas thermal conductor type. There are several types of semiconductor sensors, but here we will analyze hot-wire semiconductor sensors.

Materials and methods

The characteristics of the three sensors in hydrogen gas detection are shown below. Catalytic combustion sensor: combustible gas PT, PD. This sensor uses the combustion heat generated by catalytic combustion. In the case of flammable gases such as methane and propane, the sensor temperature must be 300 °C or higher. In this temperature range, the sensor output will be a diffusely limited area depending on the gas concentration) and can be used permanently. However, if the gas is limited to hydrogen, it is clear that it can be used at low temperatures (between 100℃-200℃). In addition, selectivity in relation to other gases can be achieved, and use in this temperature range may increase in the future. Semiconductor sensor: this sensor uses a change in electrical conductivity due to adsorption of combustible gas on the surface of the metal oxide semiconductor. The output signal is logarithmic, not linear, relative to the gas concentration. In other words, it is very sensitive at low concentrations. Using this feature, he made many advances in the detection of low concentrations, which is not possible when using catalytic burning methods. Until now, there was no sensor that would be selective to hydrogen gas and could be used permanently [2-4].

A semiconductor wire sensor with a silicon dioxide film formed on the surface of a semiconductor has a high selectivity of hydrogen (a semiconductor sensor with a thermal selective wire). In other words, the silica membrane acts as a crystalline aluminosilicates that allows only hydrogen to pass through. Figure 1 shows the characteristics of hydrogen gas and the detection concentration range of each sensor.

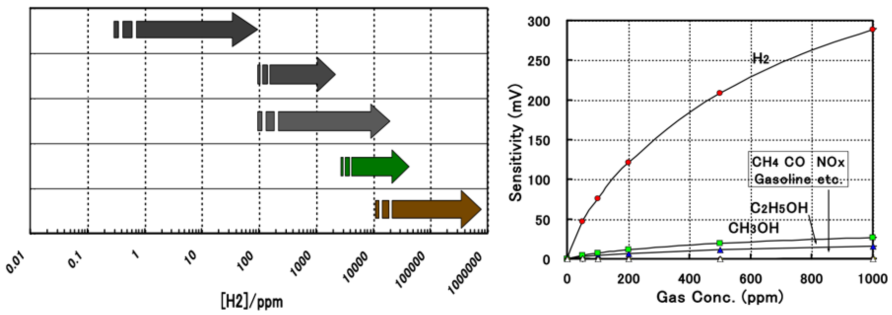

Figure 1 – Different sensor detection concentration ranges (left) and output characteristics of hydrogen selective semiconductor thermal sensor (right)

Sensors that use reactions with metals such as hydrogen at room temperature can be expected to have high selectivity over hydrogen, as they do not react with gases other than hydrogen.

Thermoelectric hydrogen sensor – The detection principle is the same, it is a catalytic combustion sensor. Thermocouples are used to determine the temperature difference. (Sage, a new type of sensor using a thin film, was introduced. As mentioned above, it is important to note that hydrogen gas is catalytically oxidized even at relatively low temperatures, as well as the technology of creating a thin film is used in the sensor configuration. The technology used in MEMS, the feature is the selectivity on hydrogen, can be operated at 100°C temperature (low power consumption) low, detection range (100~3%). Figure 2 shows the scheme of work.

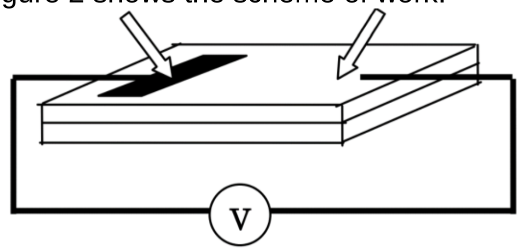

Figure 2 – The concept of operation of a thermoelectric hydrogen sensor

Solid electrolyte hydrogen sensor. Zirconium oxide (ZrO_2) with oxygen ions as a carrier yttrium oxide (Y_2O_3) is added to stabilized zirconium dioxide (YSZ) which is widely used as an oxygen sensor. Oxygen sensors use a" gas ion electrode ", which uses a gas of constant concentration (oxygen) as a comparison electrode, and an electromotive force in the equilibrium state is used (Nernst equation) [5].

High temperature is characterized by stability even at 600℃. There will also be the use of this function as a sensor to detect hydrogen, carbon monoxide, where the proposed hydrogen sensor can be used as a comparison electrode.

When measuring the concentration of oxygen in equilibrium, one electrode is used. The goal of this is to get the potential at the same time and it should be as reversible as possible. However, if, for some reason, irreversibility occurs in the electrode (reaction, etc.), an «potential opportunity» occurs. However, if this is changed, flammable gases in the air can be detected in an unbalanced way. The hydrogen sensor presented here uses stabilized zirconium dioxide and uses the equilibrium property described above [4-6]. Hydrogen gas is adsorbed oxygen present at both poles. O2 – 2 (fig. 3). Oxidation reactions occur on both electrodes, but due to the difference between the anode and the cathode electrodes, the anode prevails.

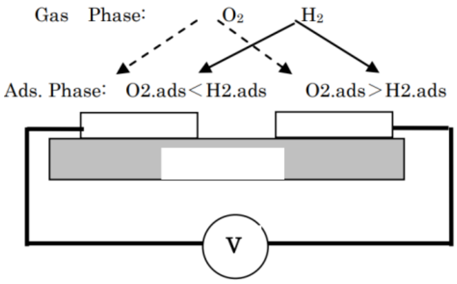

Figure 3 – The principle of operation of a solid electrolyte hydrogen sensor

More oxidation reactions occur at the electrode than at the cathode. Below are the main reactions on two electrodes in the case of hydrogen [3].

$$\text{Anode: } H_2 + \frac{1}{2} * O^{2-}_{2(ad)} \rightarrow H_2O + 2 * e^- \quad (1)$$

$$\text{Kathode: } \frac{1}{2} * O_2 + 2 * e^- \rightarrow \frac{1}{2} * O^{2-}_{2(ad)} \quad (2)$$

Full reaction: $H_2 + \frac{1}{2} * O_2 \rightarrow H_2O$

This reaction generates the following voltage on both electrodes (depending on the logarithmic concentration):

$$U_S = \frac{\Re * T_S}{n * F} * \ln \frac{C_{H2(ad,K)}}{C_{H2(ad,A)}} \quad (3)$$

Here R: Gas Constant, T_S: absolute sensor temperature, F: Faraday constant.

The peculiarity of this sensor is that it is sensitive to hydrogen gas. The answer is very fast (90% in a few seconds). However, hydrogen gas has no selectivity. It is also used as an electrolyte material for the hydrogen sensor using a conductive solid electrolyte is also being developed. You can see the sensor that uses the reaction between the 4th hydrogen gas and the metal. Here we study hydrogen-specific PDDS. Explore sensors that use reactions with metals such as metals, and this reaction can be divided into two types.

1.Metal occlusion: PDD is in atomic ratio at room temperature 0.6 can store twice as much hydrogen. This occlusion causes changes in electrical resistance, weight, and volume, and can be a sensor that uses these changes. For example, an example of a hydrogen sensor using the cantilever Principle.

2.dissociative adsorption in metal: using the phenomenon of dissociative adsorption on metal surfaces such as (H2->H+H). In this case, the effect of adsorbed atomic hydrogen is often used. For example, an electric field change via hydrogen (electric dipole) is used at the metal-insulator interface. A typical example of a MOSFET is a hydrogen sensor. An attempt was made to apply transistor technology (device technology) formed on the substrate to gas sensors. However, it is not practical as a gas sensor.

Application sensor it is clear that the hydrogen sensor is triggered based on this principle and technology (fig. 4). Since it is based on a FET (field effect transistor) made on a P-type Si substrate, it is called a MOSFET-type hydrogen sensor. (MOSMetal Oxide Semiconductor). The heater and temperature sensor are located on one chip with the sensor. The chip size is about 1.5×1.5 mm2, and the operating temperature is about 140°C, and the power consumption is less than 100 mW.

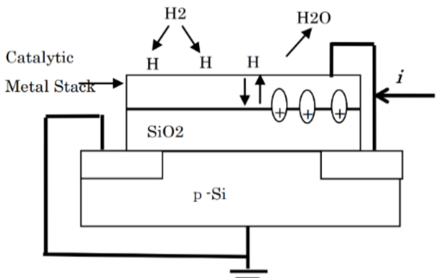

Figure 4 – Schematic diagram of the operation of a hydrogen sensor of the MOSFET type

The sensor sensing principle is based on the working principle of the field effect transistor (bipolar coupling mode). A catalytic metal stack is used as a gate for the device. Hydrogen gas in the atmosphere replaces the characteristic curve I-V of the device, as shown in Figure 5. During direct current operation, the concentration of hydrogen gas can be measured as the voltage change (ΔV) of the device.

The chemical reaction of hydrogen gas can be described as follows. Hydrogen gas is adsorbed on the surface of the metal layer of the catalyst and decomposed into hydrogen atoms (dissociation adsorption). The hydrogen atom passes through the metal layer of the catalyst, reaches the interface of the metal insulating layer, and forms an electric dipole layer at the interface. This results in a decrease in the potential of the dipole boundary layer. This field effect has the same effect as the change in the gate voltage on the transistor (the shift of the I-V curve in Figure 5). The actual reaction site of hydrogen gas and the device is the boundary layer, where only hydrogen atoms reach, resulting in selectivity. The reverse reaction is the transfer of hydrogen atoms from the boundary layer to the surface of the metal layer and the formation of water molecules. (2H+O->H2O), which is. The hydrogen sensor operates at low temperatures using a reaction with a metal as described above, the selectivity of hydrogen, in which there are many actions, such as the variety of detection signals, excellent characteristics have been performed. Next we will introduce two «hydrogen sensor that receives protons» with the characteristics of interaction with hydrogen and «photosensitive sensor for measuring hydrogen concentration» with the characteristics of signal detection.

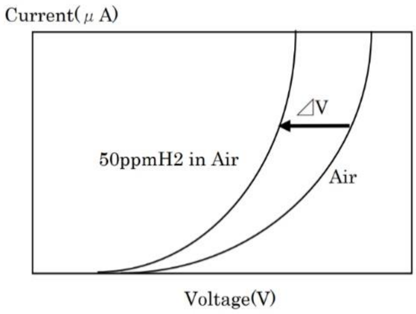

Figure 5 – Characteristics of MOSFET type hydrogen sensor V-I

Results and Discussion

Hydrogen intake sensor. Pyrrolopyrrol pigment (DPP). This pigment is insoluble in all organic solvents and is highly light and heat resistant. DPP is a pyridyl derivative of DPP. It has been found that the amount of electrical resistance of a gas is significantly reduced by protonation, and this phenomenon can be used as a gas sensor [5,7]. The design of the sensor is shown in Figure 6 (a). In the glass substrate, Naito (indium and tin oxide) comb electrode and layer (vacuum evaporation 300~400 Å). As a hydrogen protonation catalyst, PD particles are sprayed onto the comb electrode. Shown in Figure 6 (B).

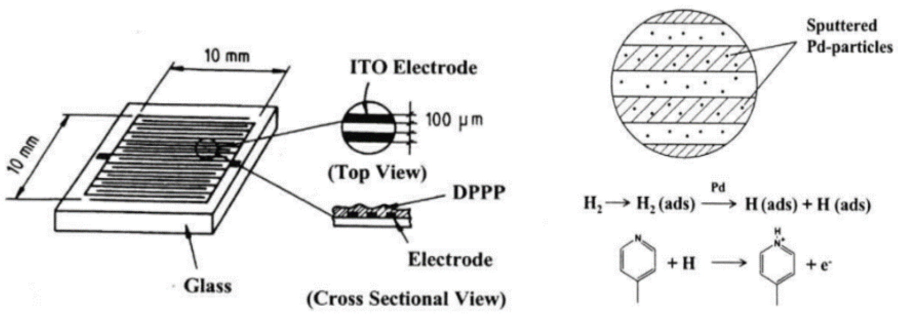

Figure 6 – the structure and working mechanism of the Proton receiving hydrogen gas sensor
of the Working Mechanism

Hydrogen molecules are physically embedded on the surface of the DPP, diffused into the DPP, and protonated by the PD catalyst to reduce the resistance value of the DPP. The peculiarity is that it works at normal temperatures. The detection concentration range will be from 500 ppm to 100% of its width.

Photosensitive sensor for measuring hydrogen concentration. The hydrogen sensor described above uses hydrogen dissociation adsorption, which is designed to electrically detect current (electrical resistance, potential, etc.). The sensor included here is a light-sensitive hydrogen sensor that detects hydrogen through an optical method.

$PdWO_3$ was known to react with hydrogen gas, giving it a blue color. A photosensitive sensor for measuring hydrogen concentration consisting of thin PD films [8-10].

However, this suggests that the reaction and return are faster than conventional hydrogen sensors of this type, and that it is also excellent in its repeatability.

Conclusions

In this work, what is at the stage of practical application as a hydrogen gas sensor and some new sensors are introduced. Currently, a research and development project is being implemented in the direction of developing key technologies for the safe use of hydrogen.as presented in this article, hydrogen is the basis for the implementation of energy distribution regulation. Based on this, we conducted an analysis that high-pressure gas for hydrogen sensors provides safety.

In particular, it is characteristic of a high reaction with a wide concentration range and the like. The gas sensor for hydrogen has the characteristics of the target gas (chemically active, good thermal conductivity, low viscosity, etc.), so it is also a sensor with the most detection principle compared to other combustible gases. Therefore, there are many other sensors at the level of practical application or in development. There is also the possibility of the emergence of sensors based on completely new ideas.

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АНАЛИЗ ДАТЧИКОВ ОБНАРУЖЕНИЯ ГАЗООБРАЗНОГО ВОДОРОДА

Газообразный водородный датчик играет важную роль в обеспечении безопасности различных отраслей промышленности, которые в значительной степени зависят от газообразного водорода высокого давления. Описаны датчики водорода нового типа, *твердоэлектролитные, металло-оксидные полупроводниковые и других типов. Газовый датчик для определения водорода обладает характеристиками целевого газа (химическая активность, хорошая теплопроводность, низкая вязкость и т.д.), поэтому он также является датчиком с наиболее эффективным принципом обнаружения по сравнению с другими горючими газами. Таким образом, существует множество других датчиков, находящихся на уровне практического применения или в стадии разработки. В настоящее время проводятся эксперименты по утечке газообразного водорода под высоким давлением и в больших количествах, и некоторые из них очевидны для широкой публики. Существует несколько методов обнаружения газообразного водорода, но использовать инфракрасный метод, который в последние годы значительно продвинулся в технологиях, невозможно, поскольку водород считается одноатомным газом, в отличие от метана. Из соображений безопасности на практике используются датчики водорода трех типов: каталитического горения, полупроводникового типа и типа газового теплопроводника. Существует несколько типов полупроводниковых датчиков, но здесь мы рассмотрим полупроводниковые датчики с термопроводом. В частности, это характерно для высокой реакции с широким диапазоном концентраций и тому подобного.*

Ключевые слова: *Датчик водорода, датчик газа, каталитическое сгорание, полупроводниковый термопровод, DPP.*

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СУТЕГІ ГАЗЫН АНЫҚТАУ ДАТЧИКТЕРІН ТАЛДАУ

Сутегі газының сенсоры жоғары қысымды сутегі газына қатты тәуелді әртүрлі салалардың қауіпсіздігін қамтамасыз етуде маңызды рөл атқарады. Сутегі датчиктерінің жаңа түрі, қатты электролит, металл оксидінің жартылай өткізгіші және басқа түрлері сипатталған. Сутегіге арналған газ датчигі мақсатты газдың сипаттамаларына ие (химиялық белсенді, жақсы жылу өткізгіштік, тұтқырлығы төмен және т.б.), сондықтан ол басқа жанғыш газдармен салыстырғанда ең көп анықтау принципі бар сенсор болып табылады. Сондықтан практикалық қолдану деңгейінде немесе әзірленуде көптеген басқа сенсорлар бар. Қазіргі уақытта жоғары қысымды сутегі газының ағуы және сутегі газының көп мөлшерде ағуы бойынша эксперименттер жүргізілуде, олардың кейбіреулері көпшілікке түсінікті. Сутегі газын анықтаудың бірнеше әдістері бар, бірақ соңғы жылдары айтарлықтай технологиялық жетістіктерге қол жеткізген инфрақызыл әдісті қолдану мүмкін емес, өйткені сутегі метаннан айырмашылығы моноатомды газ болып саналады. Қауіпсіздік мақсатында практикалық қолдануға енгізілген сутегі датчиктерінің үш түрі бар: олар каталитикалық жану, жартылай өткізгіш түрі және газ жылу өткізгіш түрі. Жартылай өткізгіш датчиктердің бірнеше түрі бар, бірақ мұнда біз ыстық сымды жартылай өткізгіш датчиктерді талдаймыз. Атап айтқанда, ол кең концентрация диапазоны бар жоғары реакцияға және сол сияқтыларға тән.

Түйін сөздер: *сутегі датчигі, газ датчигі, каталитикалық жану, жылу сымының жартылай өткізгіші, DPP.*

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ИНТЕГРАЦИЯ ИНТЕРНЕТА ВЕЩЕЙ И МАШИННОГО ОБУЧЕНИЯ ДЛЯ РАЗРАБОТКИ ИНТЕЛЛЕКТУАЛЬНОЙ СИСТЕМЫ МОНИТОРИНГА ЗДОРОВЬЯ ПАЦИЕНТА И ФАКТОРОВ ОКРУЖАЮЩЕЙ СРЕДЫ

Аннотация: *В статье рассматриваются перспективы интеграции технологий Интернета вещей (IoT) и алгоритмов машинного обучения (МО) для создания интеллектуальной системы мониторинга качества воздуха. Дополнительно описывается модуль мониторинга физиологических показателей пациента (HR, HRV-метрики SDNN, RMSSD, LF/HF, дыхательная частота, SpO_2, АД), интегрированный в единую IoT-архитектуру и конвейер анализа данных. Представлен прототип с потоковой агрегацией медицинских и средовых сигналов, правилами раннего оповещения и сценарием совместной интерпретации параметров воздуха и состояния пациента. Основное внимание уделяется использованию IoT-сенсоров, методам обработки данных в реальном времени и прогнозированию загрязнения воздуха с помощью гибридных моделей МО, включая Random Forest, Gradient Boosting Machines и Long Short-Term Memory (LSTM). Подчеркивается значимость повышения чувствительности и надежности сенсоров с применением наноматериалов, таких как полианилин, графен и углеродные нанотрубки. Акцентируется важность защиты данных, энергоэффективности и устойчивости масштабируемых IoT-систем, а также их роль в снижении экологических рисков и поддержке концепции «умных городов». Рассматриваются пути интеграции таких систем в городскую инфраструктуру, включая решения для автоматизации анализа данных и визуализации. В статье также обсуждаются перспективы внедрения интеллектуальных систем мониторинга в промышленной и жилой инфраструктуре для*