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Development of Battery-Free Long-Range Wireless Hydrogen-Gas Sensor Using High-Frequency QCM Resonator

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1. Introduction

Hydrogen gas (H_2) is an attractive environment-friendly energy carrier because it is clean and has high combustion energy and generates only water as a byproduct[1]. However, the use of H_2 in production, storage, and supply for energy applications essentially requires intense supervision as H_2 is flammable and explosive at concentrations above 4% in air. In particular, because H_2 is the smallest gas molecule and diffuses quickly, even a slight leak can cause catastrophic explosions. Thus, for the practical use of H_2, it is indispensable to find a method to monitor and manage H_2 concentrations up to 4%.

In this study, we originally developed the battery-free, wireless quartz-crystal microbalance (QCM) sensor. A QCM normally detects target material absorbed on its surface through the frequency change due to the mass-loading effect. Zhou *et al.*[2,3] showed that a quartz resonator with a thin palladium (Pd) film on its single face can be used as a highly sensitive H_2 sensor. The resonance frequency changes as the Pd thin film expands due to hydrogen absorption and the shape change of the quartz resonator. They demonstrated that this shape effect is superior to the mass-loading effect[2]. This sensor is capable of detecting low concentrations of H_2 below 10 ppm at room temperature (25 °C) by oxidizing its surface through air plasma treatment[3]. Furthermore, by incorporating a quartz resonator into a microchannel fabricated using MEMS technology, the device is portable and can be used for on-site H_2 detection. Because of its high sensitivity even under anoxic conditions, it can be used in nuclear reactor vessels, hydrogen fuel cell, and in inert gas environments such as nitrogen.

All existing H_2 sensors require wiring connections or batteries. As mentioned above, hydrogen is a flammable and dangerous gas, hydrogen-leak detection must be performed at a certain distance. However, it is not possible to maintain a certain distance when the wiring is connected to the measurement device. In addition, a wireless sensor with a battery cannot be used for a long time. Therefore, it is essential to develop a remote sensor that does not require a wiring connection and a battery.

Therefore, the goal of this research is to develop a completely remote and battery-free sensing technology. The thinner wireless QCMs have dramatically increased the frequency of oscillation with improved sensitivity, reaching the VHF (30 -300 MHz) and UHF (300 MHz -3 GHz) bands. This means that remote measurement is possible. Specifically, the resonator oscillates when an electromagnetic field is applied to the sensor remotely, enabling the development of a completely battery-free sensor that simultaneously detects hydrogen and supplies power. Once this technology is established, H_2 leakage can be detected semi-permanently from a remote location, making a significant contribution to the realization of a hydrogen society.

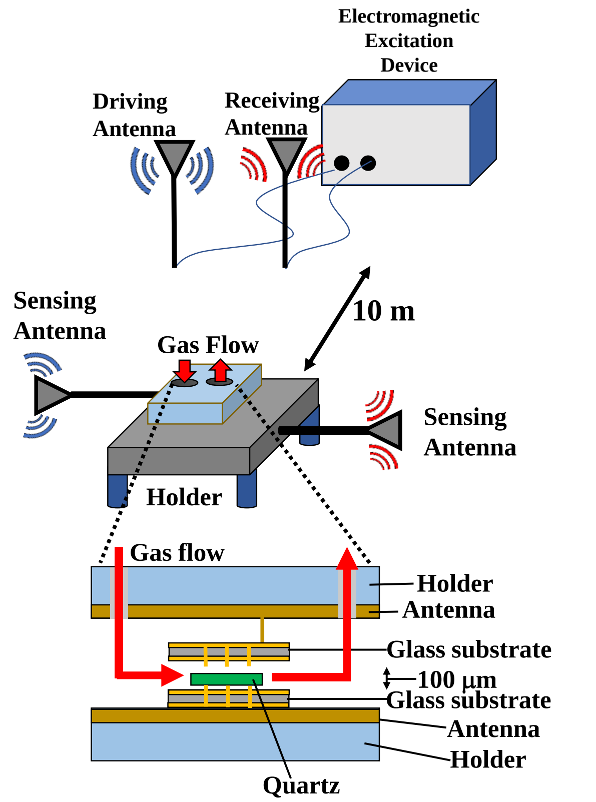

Fig. 1 Schematic of the battery-free remote hydrogen sensor.

2. Experimental procedure

Figure 1 illustrates the measurement setup.

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The AT-cut quartz resonator with the fundamental resonant frequency of 125 MHz was located inside the glass plate holder. On one side of the quartz resonator, 5 nm Cr and 200 nm Pd thin films were deposited using the magnetron-sputtering method. Microchannels are constructed on the glass plates using the MEMS technology. The quartz resonator was packaged using the anode bonding method. The fabricated MEMS QCM sensor has a size of 6 mm × 6 mm × 1 mm.

The sensor is then placed in a holder, where sensing antennas for reception and emission of electromagnetic waves are attached. A high-power electromagnetic-wave generator generates the tone-burst electromagnetic wave with the same frequency as the resonant frequency of the MEMS QCM, which remotely excites the QCM. After the excitation, the receiving antenna detects the electromagnetic wave emitted from the QCM, making it possible to measure the resonant frequency of QCM remotely with a battery-free manner.

3. Results and Discussion

First, we investigated how far the distance between the electromagnetic-wave excitation device and the MEMS QCM sensor can be separated. **Figure 2** shows the detected resonance spectrum as a function of distance. Although the intensity of the resonance peak decreases with distance, the resonance frequency is measurable even at a distance of 10 m. Although wireless sensors for detection of hydrogen[4] and nitric-oxide[5] have been proposed. These sensors fail to be operated semi-permanently because they require a battery, and the measurement distance is only a few centimeters.

In contrast, our sensor does not require a battery and can be operated without power, so it is expected to be used semi-permanently. In addition, we are able to observe signals from a distance of 10 m. In the future, we expect that further improvement in antenna design will enable efficient sensor oscillation, which will enable sensing in inaccessible locations.

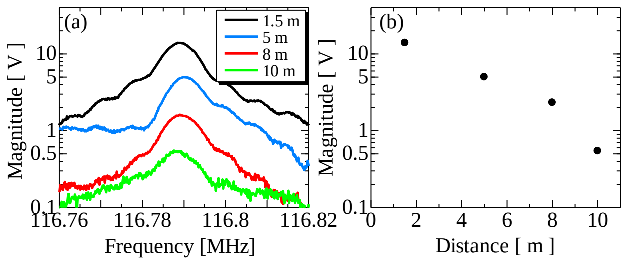

Fig. 2 (a) Resonant spectra at various distances between 1.5 -10 m of the MEMS QCM sensor and (b) relationship between the maximum amplitude and distance.

4. Conclusion

The signal from a quartz resonator with a resonance frequency of 125 MHz was observed from a distance of 10 meters. Compared to other remote sensors, this sensor is expected to have a longer range.

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