Ultra-Thin Platinum Hydrogen Sensors with a Twin-T Filter Circuit for Electrical Control of Sensitivity

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***Abstract*— A twin-T type notch filter ultra-thin hydrogen sensor has been developed to improve and control the sensitivity of the sensors. The ultra-thin platinum films were used as resistors of a twin-T notch filter, so the frequency properties of the filter change when the resistivity of the films changes by hydrogen gas exposer. Therefore, the amplitude of output signals depends on the operation frequency of the sensor. The change in the output signal of the fabricated sensor for 1%-hydrogen gas exposure was 2.9% at 1.19 kHz and 4.3% at 0.99 kHz. This result indicates that the sensitivity of the sensor could be electrically controlled by changing the operating frequency of the sensor.**

Keywords-hydrogen; sensor; ultra-thin film; twin-T; notch filter; platinum.

I. INTRODUCTION

A large amount of greenhouse gas emission from using fossil fuels cause global warming. Progressing global warming is the serious problem because that leads to environmental destruction and abnormal weather. Therefore, renewable energy is attracting attention as a new energy souse to reduce the amount of greenhouse gas. Especially, hydrogen energy is expected because the energy has the high efficiency, and the supply of the energy is stable. However, hydrogen gas (H_2) easily leaks and explodes, so the early detection of H_2 with hydrogen sensors is required for using hydrogen energy safely. Up to now, various types of hydrogen sensors, including a Catalytic-Combustion (CC) type, a Field-Effect Transistor (FET) type, and a Resistance Change (RC) type have been developed. A CC type sensor measures change in the temperature of a catalytic metal film, e.g., platinum (Pt) and palladium (Pd) by exposure to H_2. Detection with a CC type sensor is less affected by ambient conditions such as temperature and humidity. However, a CC type sensor generally operates at high temperature comparing to the other types of sensors [1-2]. So, a CC type sensor requires higher energy consumption for warming the sensor by a heater. On the other hand, a FET type sensor can operate at lower temperature. This type of sensor does not require the warming by heater, so this type of sensor can operate with lower energy consumption. A FET type sensor measures change in the work function of the catalytic metal film fabricated on the gate electrode of FET. The FET type sensor has relatively high sensitivity. However, a FET type sensor requires complicated fabrication process in a clean room [3]. The RC type sensor consists of Pd thin films on a substrate, so the fabrication process is simpler than a FET type sensor. The volume of Pd increases by absorption of H_2 into the Pd, and the resistance of the Pd changes. Thus, this type of sensor measures change in the resistance of Pd. However, the volume of Pd films change by absorption and dissociation of H_2, so Pd films irreversibly degrade [4].

In our group, a Pt ultra-thin film hydrogen sensor has been proposed and developed [5-7]. Pt film does not absorb H_2, so this type of sensor is more durable against H_2. H_2 is dissociated on the surface of Pt films, and electrons are injected into the films. Thus, the resistance of Pt films decreases while the resistivity of Pd films increases. The selectivity of similar sensor was measured at room temperature and reported elsewhere. This sensor could detect H_2 with a concentration of above 0.1 % [8].

II. METHODOLOGY

Figure 1 shows (a) the structure of the hydrogen sensor and (b) the equivalent circuit of twin-T. The Pt ultra-thin film hydrogen sensor had three layers of silicon, titanium nitride (TiN), and Pt. TiN and Pt were formed on a silicon substrate by the sputtering method. The thickness of TiN was 20 nm and that of Pt was 10 nm.

In this study, the Pt ultra-thin films hydrogen sensors were integral ted into a twin-T type notch filter circuits as resistors. A twin-T circuit has the feature that the output signals reduce at a specific frequency (notch frequency). The notch frequency (f_n) can be given by

$$f_n = \frac{1}{2\pi CR}, \qquad (1)$$

where, C is capacity, and R is resistance. Like the ultra-thin films hydrogen sensors mentioned above, the resistance decreases with increasing the concentration of H_2. Since the Pt films consists of resistive part of the circuit R, the notch frequency shifts by exposure to H_2. Figure 2 shows the schematic illustration of the frequency dependence of the amplitude and phases before and after hydrogen exposure. The notch frequency slightly increases with the exposure. Thus, concentration of H_2 could be measured by measuring the amplitude and/or phase of the output signals (V_{out}) operating at the frequency ($f_o \approx f_n$). The sensitivity (S) can be given by

$$S = \left.\frac{dV_{out}}{df}\right|_{f=f_n} \qquad (2)$$

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Because the sensitivity depends on the differential of the properties along with the frequency, the sensitivity of this type of sensor could be electrically controlled by changing the operation frequency.

III. EXPRIMENTS AND RESULTS

Figure 3 shows the change in the amplitude and phase of the output signals as time at 1.19 kHz which was the notch frequency of the circuit without hydrogen exposure. The sensor was exposed to gas balanced by 20%-oxygen and 80%-nitrogen gas (Air) for 5 min and 1%-hydrogen gas of whose pressure balanced by 20%-oxygen and 80%-nitrogen gas to be 1 atm for 5 min. The change in amplitude and phase were 2.8 % and 4.8 deg.

Figure 4 shows the change in the amplitude and phase of the output signals as a function of the operating frequency of the circuit when the sensor was exposed to 1%-hydrogen gas. The change rates depend on the operation frequencies and maximize at the frequency of 0.99 kHz and 1.19 kHz for the amplitude and the phase, respectively. The corresponding changing rates were 4.3% and 2.9%. This result clearly indicates that the sensitivity of the sensor could be electrically controlled by changing the operating frequency.

IV. CONCLUSION

In our group, the ultra-thin Pt hydrogen sensor was developed using the twin-T circuit. The sensor could be electrically controlled by changing the operating frequency. The variation of sensor properties by the fabrication process can be reduced, therefore, a series of sensors with a uniform sensitivity can be realized.

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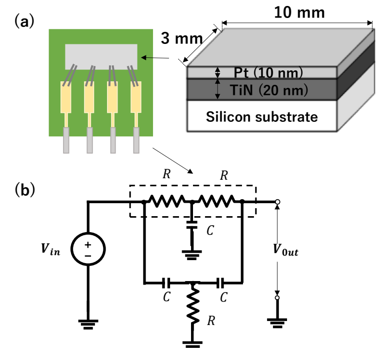

Figure 1. (a) Structure of the hydrogen sensor and (b) the equivalent circuit of twin-T

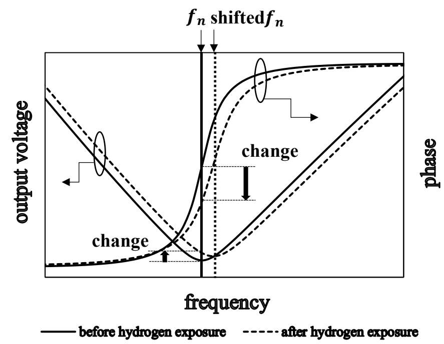

Figure 2. The schematic illustration of the frequency dependence of the amplitude and phase before and after hydrogen exposure

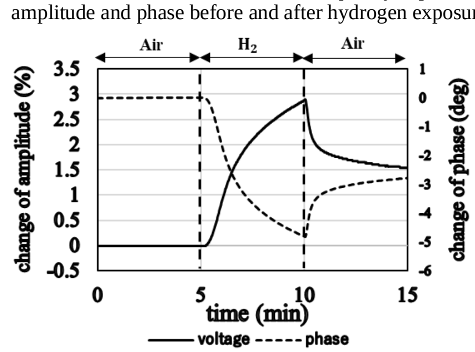

Figure 3. The change in the amplitude and phase of the output signals as time at 1.19 kHz which was the notch frequency of the circuit without hydrogen exposure.

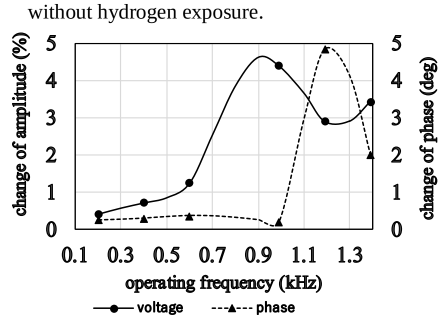

Figure 4. The change in the amplitude and phase of the output signals as a function of the operating frequency of the circuit

