Evaluation of response time in ball surface acoustic wave hydrogen sensor

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1. Introduction

Hydrogen fuel cells are expected as the most promising clean energy source. However, since hydrogen is an explosive gas, security of fuel cells requires high performance hydrogen sensors. The surface acoustic wave (SAW) excited on a spherical surface under a specific condition is naturally collimated, realizing ultramultiple roundtrips along an equator of the sphere [1-3]. The ball SAW hydrogen sensor based on this effect realized the high performance, such as high sensitivity and wide sensing range, and indicated that the 1mm \( \phi \) quartz ball SAW sensor could detect hydrogen in 10 ppm to 100% concentration range [3]. Moreover, we investigated the effect of temperature on the response and found that the response time is reduced by heating to 124 °C [4].

In this study, we evaluated response time in 1mm \( \phi \) ball SAW hydrogen sensor by a new measuring method as well as the previous method.

2. Equipment for sensor evaluation

Fig. 1 shows the previous setup[3,4]. The 1 mm \( \phi \) quartz ball SAW sensor with 40 nm thick Pd-Ni film was exposed to hydrogen at concentrations from 0.1 % to 3 % by using a flow cell using mass flow controllers (MFCs). And the waveform was recorded by a digital oscilloscope and computer [4].

The measurement interval was limited to 2 s due to the 20 times integration of waveforms in the digital oscilloscope. Therefore, we developed a faster digital quadrature detector (DQD) shown in Fig. 2 and evaluated response time of the sensor. In the DQD, 150 MHz SAW was excited and received, and then it was converted to the intermediate frequency (IF) signal at 6.25 MHz by the heterodyne detection. The IF signal was then digitized at a sampling rate of 25 MS/s (four times of IF). And the cosine and sine components were obtained by the quadrature demodulation of the digital signal in a field programmable gate array.

We integrated these data 256 times and obtained the phase by calculating arctangent. Using this method, the phase was measured in 0.256 s intervals.

3. Experimental results

Fig. 3 (a) shows an ultramultiple roundtrips waveform of the SAW and more than 100 turns are shown. In (b), the SAW at 50 turns is shown with an excellent signal to noise (S/N) ratio.

Fig. 4 shows delay-time response of this ball for 0.1 ~ 3.0 % hydrogen concentration. The
temperature compensation was applied using measured temperature data shown at the top of Fig. 4. The response time of the sensor was found to be in the range of 2 ~ 5 s.

![Figure 3](image.jpg)

Fig. 3. (a) Ultramultiple roundtrips and (b) waveform of SAW at 50 turns.

![Figure 4](image2.jpg)

Fig. 4. Responses for 0.1 ~ 3.0% hydrogen at RT.

The delay time response for 3.0 % hydrogen using DQD is shown in Fig. 5. The S/N ratio of the response curve in Fig. 5 was higher than that in Fig. 4. It is probably due to the larger number of integration, irrespective of the shorter measurement interval. It clearly shows the advantage of the DQD. The measurement interval was 0.256 s and the response time, defined as time required for the delay time to reach 90% of the total change, was less than 1 s. Therefore, it was found that the response in Fig. 4 was slower due to averaging in digital oscilloscope. The response time of less than 1s is one hundredth of the response time in previous SAW hydrogen sensors [5], and it is faster than that of FET sensor or of resistivity sensor. Moreover, the sensor can faster detect hydrogen at high temperature [4], and in this case, we can evaluate the accurate response time by decreasing the integration time of DQD.

![Figure 5](image3.jpg)

Fig. 5. Response for 3.0 % hydrogen using DQD.

4. Conclusions

In this study, we developed the digital quadrature detector (DQD), and evaluated the response time of the ball SAW sensor. As the result, we found that the response time is less than 1 s.

Acknowledgment

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References