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# Ball SAW sensor and its applications

# ボール SAW センサとその応用

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## 1. Introduction

It was discovered by the authr's group that surface acoustic wave (SAW) on a ball has a unique feature of multiple roundtrip propagation along a narrow path on the surface of ball [1]. Subsequent theoretical work predicted a naturally collimated beam eliminating the diffraction effect, which was experimentally verified by using a piezoelectric transducer and a laser probe [2,3]. Practical ball SAW device was developed using a piezoelectric crystal ball [4] with an intergigital transducer (IDT) of a proper width, i.e., square root of diameter and wavelength [3].

Hydrogen sensor with a Pd sensitive film absorbs hydrogen, causing change of elasticity. By virtue of the enhancedresponse due to the multiple roundtrips, very wide range hydrogen sensor, from 0.001% to 100% [2]. Ball Saw sesor has been applied also to a detector of micro gas chromatograph [5].

In highly pure gasses for semiconductor and energy industries, it is necessary to measure trace moisture less than 1 μ mol/mol (frost point -76 ℃), but the sensitivity and response time of present sensors are not sufficient. On the other hand, a ball SAW sensor achieved the measurement of 1 μmol/mol in 15 s using a delay time response [6]. Recently, we developed more sensitive and fast ball SAW trace moisture sensor [7,8].

## 2. Ball SAW sensor

The principle of the ball SAW sensor is illustrated in Fig. 1 (a). A sensitive film is deposited on the equator of a ball, on which a collimated beam of SAW is generated by an interdigital transducer (IDT) and detected by the same IDT after one, two and many turns. The velocity and attenuation of SAW are changed by the absorption of molecules into the sensitive film. Although the change is small for a very low concentration, it is amplified after ultramultiple roundtrips (more than 50 turns). If the attenuation coefficient variation multiplied by the circumference of the sphere is $\Delta\alpha L = 10^{-3}$, the relative amplitude after one turn is $\exp(-\Delta\alpha L) = \exp(-10^{-3})$ = 0.999, which is practically indistinguishable from unity. However, the relative amplitude in ball SAW sensors after 100 turns is $\exp(-100\Delta\alpha L) = \exp(-0.1) = 0.905$, whose difference from unity can easily be detected.

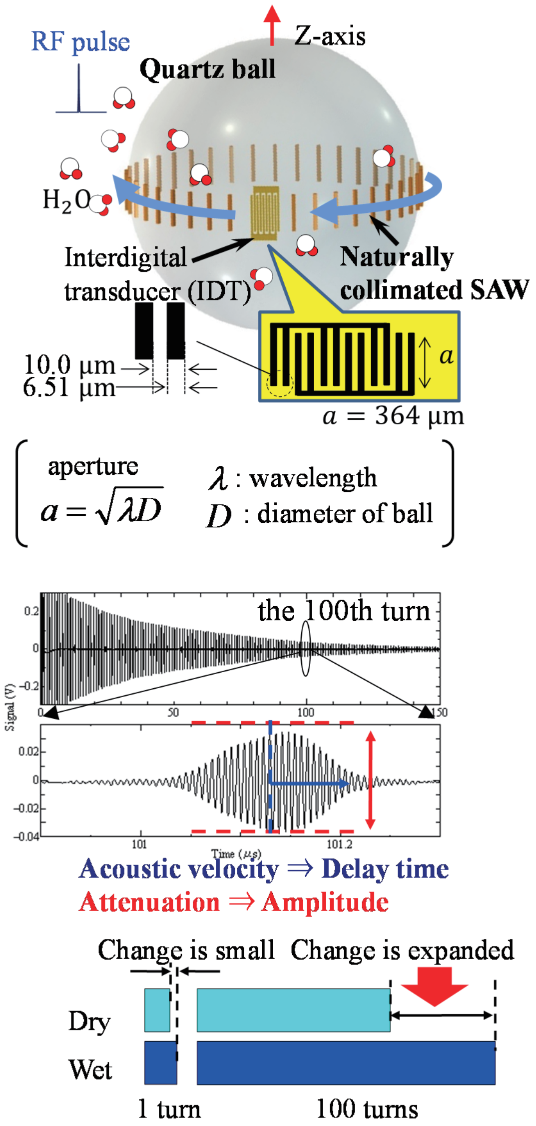


Fig.1 Principle of ball SAW sensor.
(a) Naturally collimated beam of SAW.
(b) Waveform at 100 turns on a 1 mm diameter quartz ball. (c) Principle of sensitivity enhancement after multiple turns.

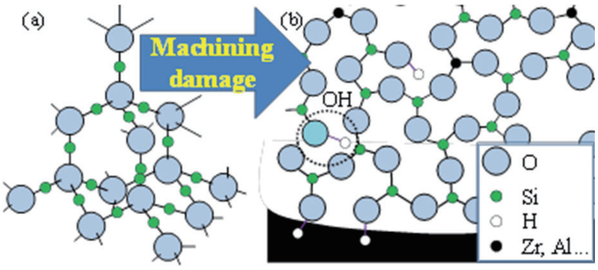


Fig.2 Structural change of quartz by machining damage or film deposition. (a) Crystalline quartz (b) amorphous silica.

### 3. Trace moisture sensor with SiOx film

Damaged layer or amorphous silica layer with sol-gel silica (SiOx) film shown in Fig. 2 has a significant sensitivity to water. For the latter, tetraethoxysilane was hydrolyzed and polymerized with an acid as a catalyst to obtain SiOx. A harmonic ball SAW sensor (quartz, ϕ3.3 mm, 80 MHz, 240 MHz) that can compensate the temperature effect [9] (Fig. 1 (a)).

A result of trace moisture measurement is shown in Fig. 3, where the concentration was gradually increased every 3 h. Fig. 3(a) shows the response at 80 MHz and 240 MHz. Though the response at more than 80 nmol/mol was clear, it was disturbed by the temperature drift. Fig. 3 (b) shows the difference between the two frequencies. The response was clear even at 6 and 19 nmol/mol. Fig 3 (c) shows the response the cavity ring sown spectroscopy (CRDS), the most sensitive and accurate commercial moisture sensor. It gave a clear response at 19 nmol/mol, though the change between 6 nmol/mol was unclear. Moreover, the response did not completely follow the humidity change. Thus, the measurement of trace moisture at the level of 10 nmol/mol was demonstrated by the ball SAW sensor. Theresponse was even faster than that of the CRDS.

In another measurement, negative shift was observed from 0℃ to -40℃, and positive shift was observed from -40℃ to -95℃. Switching from the negative to positive shifts can be explained by the mass loading dominant in high concentration, and the elastic loading dominant in low concentration [6,7].

### 4. Conclusion

The principle and applications of the ball SAW sensor was described. It was demonstrated that a highly sensitive sensors with long-term stability can be developed or many gasses.

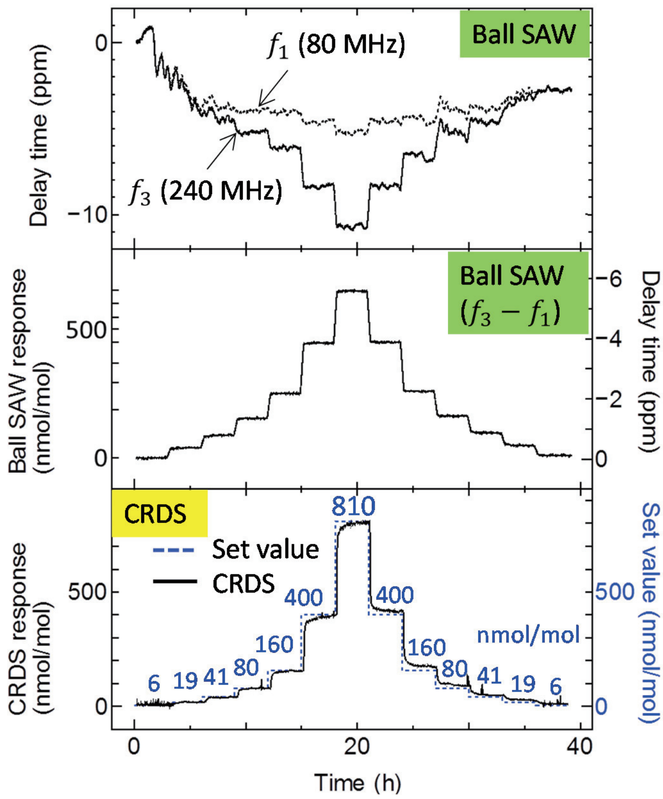


Fig.3 Responses to $N_2$ gas at 6 to 810 nmol/mol.
(a) 80 and 240 MHz ball SAW sensor
(b) Subtracted response of ball SAW sensor.
(c) Response of CRDS.

### 6. References

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