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Pressure Characteristics of Leaky Loss and Velocity on Ball SAW Device
ボール SAW デバイスにおける漏洩減衰と速度の圧力特性

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1. Introduction

Surface acoustic waves (SAW) are depending on material properties and are sensitive to physical parameters. Thus, SAW devices exhibit promising solutions in sensor applications. In a ball SAW sensor, naturally collimated beam propagates and makes ultramultiple roundtrips [1]. We developed a hydrogen sensor with wide dynamic range [2], and a compact gas chromatography. In addition, mobile-digital quadrature detector (m-DQD) which can measure RF signal response of a ball SAW sensor was developed. Coventionally, different gas pressure sensors have been used for each range, and wider range sensor is demanded [4]. Since ball SAW sensor can sensitively detect small pressure change, it is expected to be applied to vacuum sensor. In this study, we measure change of the leaky loss and the velocity of SAW when the pressure is changed, and discuss the mechanism.

2. Change of the leaky loss due to the pressure

Using quartz and langasite ball SAW device (φ3.3mm) with the same crystal symmetry class, we evaluated the relationship between attenuation constant α and physical constants of crystals when the pressure was changed. In these devices, spatial periode of interdigital transducer (IDT) was fixed to obtain a center frequency of 152.5MHz. These devices were set in a vacuum chamber, and the pressure was varied from 4Pa to 10^5 Pa. An impulse signal was transmitted to the SAW device, and received waveform was measured with an oscilloscope at each pressure. A peak value at each turn of SAW was obtained from the waveform, and the α was calculated from the slope in the semi logarithmic plots.

The amplitude of the SAW in the quartz device at the pressure of 101,325Pa (atmospheric pressure) and 4Pa are shown in **Fig. 1** (a) and (b), respectively. The roundtrip was well fitted to a single exponential function and α[dB/m] was calculated by the slope from 50 to 300 μs. In Fig.1 (a) α= 42.640, and in (b) α= 23.191. The attenuation coefficient α is expressed as

$$\alpha = \alpha_L + \alpha_P \qquad (1)$$

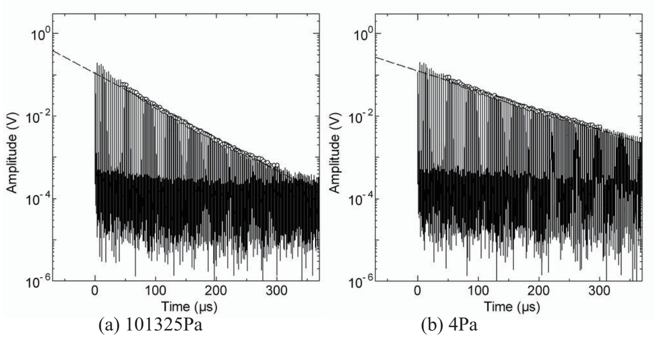

Fig.1 SAW amplitude at (a) 101,325 and (b) 4 Pa

where α_L is attenuation constant of leaky loss and α_p is the rest of losses. Theoretical values of α_L were calculated and value of α_p was added to them, to obtain the best fits of α to the experimental value.

Fig. 2 shows the theoretical and experimental value of α as functions of pressure. As the pressure decreased, α decreased and was nearly constant under several hundred Pa. Note that the experimental value almost agreed with the theoretical value.

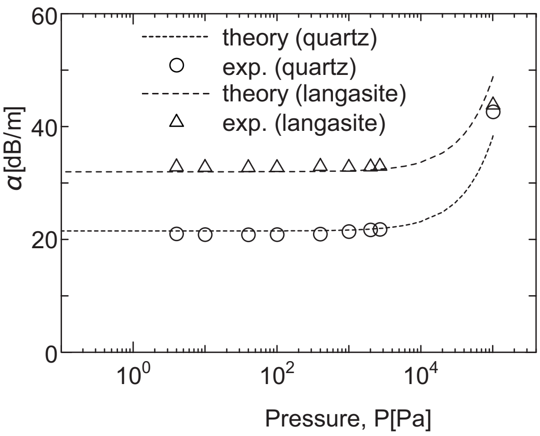

Fig.2 SAW attenuation coefficient α as a function of vacuum pressure

3. Amplitude response in the changing pressure

Using m-DQD, we examined the sensitive detection of SAW amplitude caused by the leaky loss. Quartz ball SAW device was set in the vacuum chamber and the pressure was changed continuously. The amplitude of SAW at 50 turns and the output voltage of Pirani gauge were measured, as shown in **Fig.3**. In Fig.3, evacuation with a rotary pump was started at 1 min. The Pirani gauge output showed a transition from the convection regime to Knudsen regime, but the output was nonlinear in the pressure range higher than Knudsen regime. This range was hence not suppoted in the particular gauge used here (ULVAC). But the SAW amplitude changed more than 10dB in this range, so the possibility of highly sensitive measurement in this range not supported by the Pirani gauge is suggested.

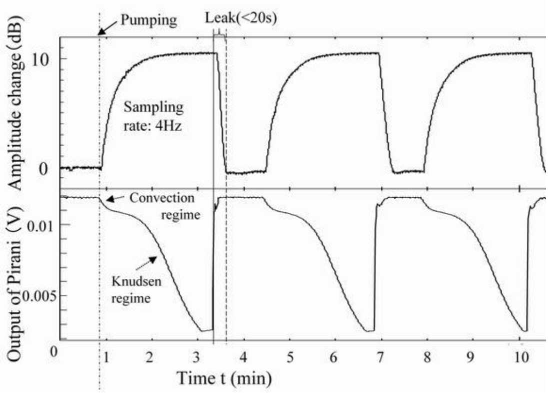

Fig.3 Transient response of amplitude of ball SAW sensor and Pirani gauge

4. Delay time response in changing pressure

Next, the delay time change caused by the SAW velocity change was investigated. The temperature at tens of mm away from the device was measured with a thermocouple. The temperature, delay time change, amplitude change, and the output of pirani gauge were recorded when the pressure was changed as shown in **Fig. 4**. When the pressure was rapidly increased by the air leak at 10 and 25 min, the temperature showed a spike-like behavior with a sharp increase and decrease. This behavior is interpreted as a result of a temperature rise by an adiabatic compression and a cooling by a heat conduction of the air.

Meanwhile, the delay time change also showed a spike. The polarity of the the change is consistent with the temperature coefficient of quartz ball [6]. But, the spike was sharper than that of the thermo couple. We propose that it is because the energy of the SAW is concentrated within the depth of 22μm equivalent to the wavelength, so the velocity changed immediately in response to the rapid change of the temperature. The air leak at 100 min caused no spike in the temperature and the delay time. It is because this leak is slow and the adiabatic compression was slow, so the change of the temperature was also slow. But, after the temperature returned to the original temperature before the pressure increase, the delay time change continued increasing. It is supposed that this phenomenon reflects the time required to conduct the heat to the whole device determined by the thermal capacity of quartz.

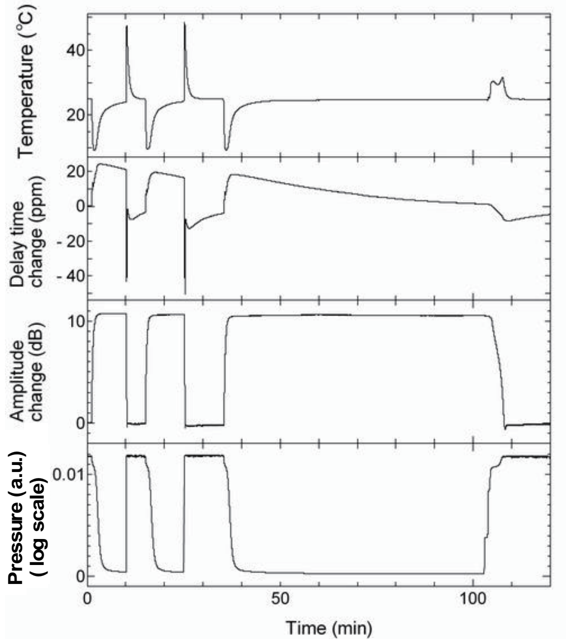

Fig.4 Transient response of temperature, delay time, amplitude and Pirani gauge (Pressure)

5. Conclusion

Using ball SAW sensor, experimental values of the leaky loss which almost agreed with the theory. Next the pressure was changed continuously, and amplitude and delay time change of the SAW were measured. The amplitude change of more than 10dB was obtained. It is suggested that this sensor can measure both pressure and temperature of gas by combining the measurement of the delay time and amplitude. This result is useful for improvement of ball SAW device and application to a wide range pressure sensor.

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