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Evaluation of SAW-type Vibration Sensor using LTGA Crystal
LTGA 結晶を用いた SAW 型振動センサの評価

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1. Introduction

Recently, the social consciousness for security and the relief have been gradually growing. Security market and the safe monitor market of the building tend to spread. In the security market especially, security system adoption rates to the house increase rapidly. Almost thieves broke into a house through a window. So, glass destruction sensor attracts attention.

There are some methods of glass break detection. For example, the sound of glass breaking is detected with the microphone, and AE (acoustic emission) wave that is peculiarity glass breaking is converted electric signal by using the piezoelectric ceramic.
These methods need detector head (microphone, piezoelectric ceramic, and so on) and Signal processing circuit, RF circuit and battery. It is difficult to miniaturize and cost-cut it and maintain these sensors, because these each parts are unified. In particular in the case of the microphone, It is a problem that misconception rate is high.

the future of our passive type vibration wireless sensor(1) with SAW (Surface Acoustic Wave) resonator is no circuit and no battery, so, it is possible to miniaturize and install anywhere.

This sensor monitor the difference of SAW impedance on the piezoelectric material, when the material receive forced motion and resonance vibrate. Because it uses the resonance vibration, it can be sensing sensitivity AE wave which vibration magnitude is very small.

We use LT($LiTaO_3$), LGS($La_3Ga_5SiO_{14}$) for sensor because of characteristic coupling factor, velocity and Q factor. LGS is high Q material compare with LT, and it becomes high sensitivity vibration sensor. We use LTGA ($La_3Ta_{0.5}Ga_{5.3}Al_{0.2}O_{14}$) in this research. LTGA is almost same crystal structure as LGS, so it will be high Q material. It is reported that LTGA has small temperature dependence as same as quartz. So it is expected that the sensor will have good temperature characteristic.

2. Design and fabrication

Figure 1 shows a schematic diagram of the vibration monitoring system, which includes an interrogation unit and a vibration sensor unit. The sensor unit is composed of the piezoelectric crystal cantilever beam, a single-port SAW resonator with an inter-digital transducer (IDT) connected to an external antenna

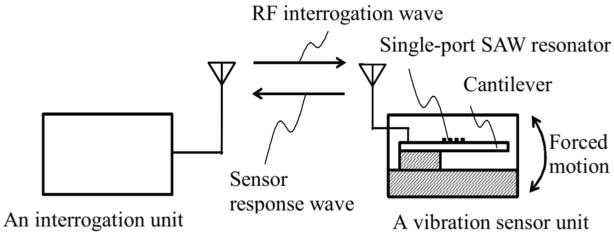
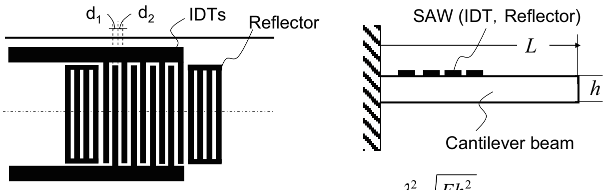


Figure 1. Schematic diagram of a vibration monitoring system



$$f_s = \frac{v}{\lambda} = \frac{v}{2(d_1 + d_2)}$$

$$f_n = \frac{\lambda^2}{L^2}\sqrt{\frac{Eh^2}{12\rho}}, (\lambda = 1.875)$$

Figure 2. Single-port SAW resonator placed on a cantilever

The spectrum of the modulated signal, which contains sidebands with a separation of mf, is presented as:

$$m(t) \approx A \cdot \cos(w_c t) + \frac{m_f \cdot A}{2}\cos(w_c + w_n) \cdot t - \frac{m_f \cdot A}{2}\cos(w_c - w_n) \cdot t$$

where A and w_c are the amplitude and angular frequency of the unmodulated carrier wave, respectively, $m_f = \Delta f / f_m$ is a modulation index, Δf the maximum frequency deviation, fm the frequency of the modulated signal, which coincides with the frequency of the external vibrations, w_n is resonant angular frequency of the cantilever.

The amplitudes of sideband signals, which include the information of the vibration, depend on the modulation index fm. Δf is proportional to the external force applied to the sensor and indicates the maximum value at the resonant frequency of the cantilever. When the cantilever has high mechanical Q, the cantilever continues free-vibration, even if a destructive impulse force is applied. Therefore, the information of the destructive impulse force is continuously captured by the proposed sensor system.

Figure 2 shows the top view of the single port SAW resonator placed on the root of the cantilever beam in order to maximize the deformation of the IDT finger electrodes. In the present experiment, we designed and fabricated the SAW resonator with the resonant frequency of 670 MHz (= $v/2(d_1+d_2)$), velocity v: 2750 m/s, finger width d_1:1um, gap spacing d_2: 1um), on the LTGA crystal cantilever.

Figure 2 also shows the cross-section of a cantilever made of LTGA. External vibrations cause

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the bending in the cantilever. As shown in next formula, mechanical dimension of cantilever determine vibration frequency(f_r)

$$f_v = \frac{1.875^2}{L^2}\sqrt{\frac{Eh^2}{12\rho}} \quad ,$$

where L is length of cantilever, h is thickness, ρ is density, E is dielectric constant. Cantilever resonant frequency is 60kHz which is AE wave region. The signal and the noise which include vibration can be classified by using this frequency.

3. Experiment and result

Table 1 shows fundamental characteristics velocity and coupling factor of piezoelectric crystal. The characteristics of LTGA is almost same as LGS. The SAW type resonator was designed based on this data.

Table.1 Fundamental characteristics of piezoelectric crystal

	LTGA	**LGS**	**$LiTaO_3$**
velocity **(m/s)**	**2200～2800** **(Y0°) (Y90°)**	**2740**	**4740**
Coupling factor **k^2 (%)**	**0.05 ～ 0.6** **(Y45°) (Y75°)**	**0.32**	**11.3**

LTGA with cut angles Y48.5 deg., and the SAW propagation direction with Euler angles of (0, 138.5, 26.6), which is the longitudinal axis of the cantilever, are chosen. The cut angle is same as LGS crystal. After cutting, IDT (line and space are 1um) was patterned on the wafer, then the cantilever beam was cut out using a dicing saw. Figure3 shows photograph of the vibration sensor.

There are 2 peaks (640MHz, 649MHz) in S11 characteristic of fabricated SAW resonator. Velocity of LTGA is smaller then that of LGS.

The fabricated sensor was characterized using a setup schematically. The setup is composed of an accelerator applying the vibration force to the sensor, a laser Doppler vibrometer detecting the vibration signal and an interrogator unit having a signal generator and a spectrum analyzer. vibration frequency is 60kHz.

Figure 4 shows the response wave spectrum under the vibrated condition at the cantilever resonant frequency 60kHz. There are obviously two sidebands with a separation of 60 kHz on each side of the carrier of 649MHz under the vibrated condition, while no sideband exists under the static condition. Therefore, the carrier wave of 641MHz is frequency modulated by the vibration signal of 60kHz.

Same sideband was confirmed second peak carrier(649MHz).

Figure5 shows the temperature dependence of the resonant frequency of SAW resonator based on LTGA(X 0deg). Frequency shift is only 1MHz within the range of 130℃ The result more than the equal to LGS was obtained.

4. Summary

The Bulk characteristic and surface acoustic wave characteristic of LTGA was investigated and it is almost same as LGS crystal. Glass break sensor using LTGA was fabricated. The high frequency vibration signal of 60kHz which is AE wave region was successfully detected. The carrier frequency is 670MHz band in this research. This result suggests that it is possible to use in 950MHz UHF band.

Figure 3. Photograph of the vibration sensor

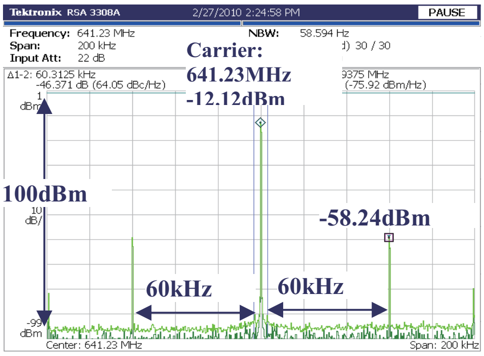

Figure 4. Response wave spectrum under dynamic condition at the cantilever resonace frequency of 60 kHz

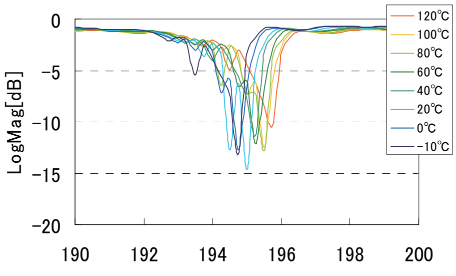

Figure 5. Temperature dependence of SAW resonant frequency

We use the LTGA which cut angles is same as general LGS wafer, in this research. Best angle of LTGA for SAW devises is might exist. Further sensitivity improvement can be expected by searching best angle.

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References

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