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Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 3-4
8-10 November, 2011

Experimental Study of Highly Sensitive Strain Sensor Using a Surface Acoustic Wave Resonator for Wireless Monitoring System

無線観測システムのための表面弾性波素子を用いた高感度ひずみセンサ

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1. Introduction

Wireless sensors are developed actively in many reserch groups, and open up various new applications such as RF tags or tire pressure monitaring systems (TPMS) [1][2].

The wireless sensor can be classified to "passive type" or "active type". The latter is mounted a battery and some active circuits with a sensor unlike the former. The active wireless sensor has long effective communication range, and facilitates constructing a mesh of sensors. It allows us to measure the physical quantity as a distribution.

This feature is effective for a maintenance of giant infrastructures such as bridges, skyscrapers or power plants. Furthermore it can facilitate large-scaled enviromental observations like a monitoring stress in the earth crust. For these applications, a strain is one of the most important physical quantity to be monitored.

Figure 1 shows a schematic of the wireless system of the strain sensor. A surface acoustic wave (SAW) resonator is mature as a sensor which detects humidity, viscosity, pressure or temperature with high sensitivity [3], and is compatible to impliment the RF system. So we chose the SAW resonator to measure the strain.

The strain sensor must be bonded itself diretly on the object to be measured. This is an inherent and plactical issue of strain sensors. In this report, the SAW strain sensors were fabricated on $LiNbO_3$ and quartz, and applied to the tensile test plactically by attaching the specimen SS400 based on the Japan Industrial Standards (JIS).

2. Principle and Design

When the SAW resonator is subjected to external force, a pitch of interdigitated transducer (IDT) varies depending on the strain. Assuming that the acoustic velocity is invalid under the stress, the strain can be calculated by a frequency shift as below:

$$\varepsilon = \frac{f_0 - f_s}{f_s} = \frac{\Delta f}{f_s} \tag{1}$$

where f_0 and f_s are resonant frequency in an initial and a strained state, respectively.

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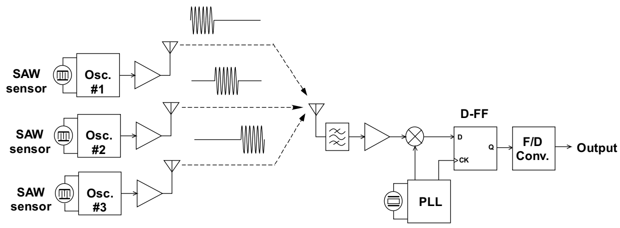

Fig. 1 Schematic illustration of the wireless monitoring system

TABLE I. Design parameters of the SAW sensors

Material	$LiNbO_3$	Quarts
Cut angle	128°Y-X	AT
Pitch	5 μm	5 μm
Duty	50 %	50 %
Aperture length	200 μm	200 μm
# of pairs (IDT)	30	30
# of pairs (Reflector)	90	90
f_0 (target value)	398 MHz	316 MHz

Table I shows design parameters of the SAW strain sensor. In our design, measurable minimum strain ε_m reaches 10^{-6} order. It is much higher than the commercial strain gauges ($\varepsilon_m > 10^{-5}$).

3. Fabrication

Fabrication process of the SAW sensor is indicated below. At first, piezoelectric substrate was cleaned in organic solvent. And then, aluminum (Al) was deposited in thickness of 200 nm using an RF magnetron sputtering, and patterned photolithographically by the etchant, which is diluted compound liquid of H_3PO_4, HNO_3, and CH_3COOH. **Figure 2** shows a optical micrograph of the fabricated IDT pattern.

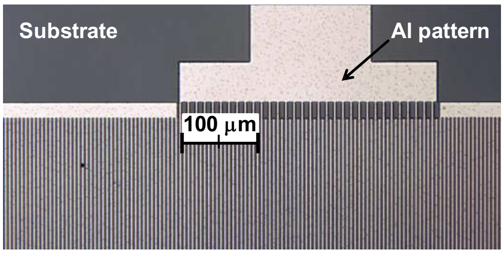

Fig. 2 Optical micrograph of the IDT pattern

Fabricated sensors of $LiNbO_3$ and quartz operated in resonant frequency of 391.6 MHz and 310.9 MHz, Q factor of 843 and 1984, respectively.

4. Evaluation

The quartz based strain sensor was bonded to the SS400 by the acrylic adhesive (KYOWA: CC-33A). **Figure 3** shows the influence of the bonding. It was observed that the resonant frequency was downshifted after bonding. This result is caused by the buckling of SAW sensor due to a cure shrinkage of the adhesive. Same result was observed in the $LiNbO_3$ based sensor as well.

We evaluated the influence of temperature and hymidity for the sensor fixed on the SS400. Results are summarized in **TABLE II**. The relativity of temperature was different from the theoretical value ($LiNbO_3$: -75 ppm/°C, Quqarts: 0.0 ppm/°C) [4]. This is a influence of low relativity of the SS400. The relativity of humidity was depend on the Q factor. It is expected from this result that the absorption of the water plays a mass loading to the resonator.

The tensile testing was executed using the SS400 on which the sensor was attached. Circles plotted on the **Fig. 4** indicate the measured data from the tensile testing machine (A&D; STA-1150) as a reference. Filled circles indicate the data from the wired SAW strain sensor. It was confirmed that each data was muched well, and the developed sensor could detect the strain of 10^{-6} order.

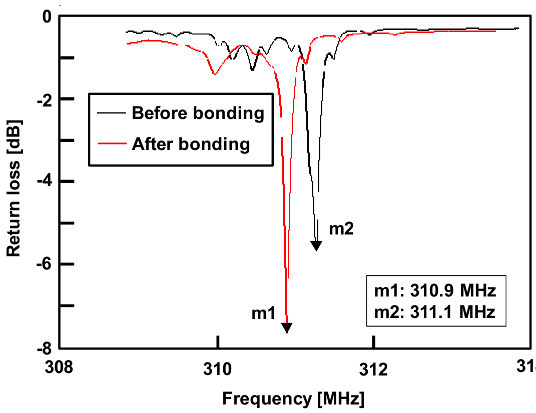

Fig.3 Resonance characteristics of the quartz strain sensor

TABLE II. Relativities for temperature and humidity

	$LiNbO_3$	Quartz
f_0	391.6 MHz	310.9 MHz
Q	843	1984
Relativity for Temperature	-68 ppm/C°	0.00 ppm/C°
Relativity for Humidity	-0.46 ppm/%	-1.1 ppm/%

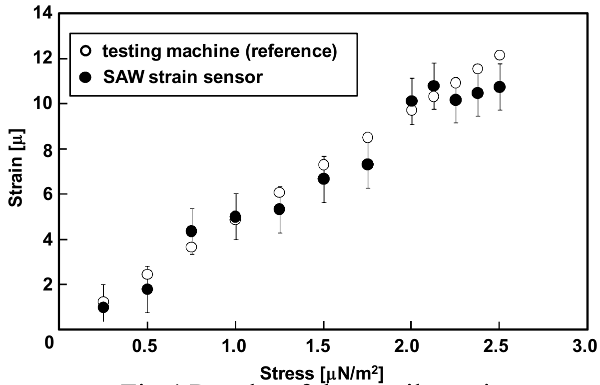

Fig.4 Results of the tensile testing

5. Conclusion

An active wireless sensor is usefull to monitor the stress straged in giant infrastructures or the earth crust for disaster prevention.

In this study, we developed the highly sensitive strain sensor using a surface acoustic wave (SAW) resonator for constructing the monitoring system. Developed sensors were practically applied to the tensile test based on the Japan Industrial Standards (JIS).

As a result, it was confirmed that the developed sensor could detect the strain of 10^{-6} order with linearity. It is much sensitive for commertial strain gauges.

Acknowledgment

This work was conducted under the project "Research of a nano-energy system creation" (No.18GS0203), funded by the Ministry of Education, Culture, Sports, Science and Technology (MEXT).

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