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Resonance Properties of Shear-Horizontal Surface Acoustic Wave on $Ca_3TaGa_3Si_2O_{14}$ at High Temperature

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1. Introduction

Battery-powered wireless sensors have been applied in environments that are inaccessible to humans, but these sensors have problems such as the need for periodic battery replacement. Surface acoustic wave (SAW)-based sensors are utilized as maintenance-free sensors because they can wirelessly measure temperature, pressure, and strain without without the need for batteries[1,2]. In particular, the temperature of steam turbines used in nuclear and thermal power plants reaches up to 600°C, and wireless sensors that can be used in such high-temperature environments are required.

The authors previously reported shear horizontal SAWs (SH-SAWs) with highly stable and high-resonance *Q* on a new langasite-type piezoelectric single crystal, $Ca_3TaGa_3Si_2O_{14}$ (CTGS)[3,4]. Since CTGS retains piezoelectricity up to its melting point of 1,200°C, a SAW sensor for such high-temperature environments can be expected by utilizing SH-SAWs on CTGS.

In this study, the resonance properties of the SH-SAW resonator fabricated on CTGS by forming an interdigital transducer (IDT) using gold (Au) thin film were evaluated experimentally up to 500°C, and the second-order temperature coefficient of the elastic constant of CTGS was determined to estimate the temperature characteristics of SH-SAW on CTGS with any cut angle.

2. Resonance Property of SH-SAW at High Temperature

The previously reported Au-IDT/CTGS(0°, 134°, 90°) and Au-IDT/CTGS(0°, 155°, 90°) SAW resonators[3,4] were used in the measurements. For the Au-IDT/CTGS(0°, 134°, 90°) SAW resonator with a wavelength λ of 32 μm, a number of finger pairs *N* of 70.5, and a reflector number N_R of 25, the Au thin-film thickness *h* and the normalized film thickness (*h*/λ) were 0.66 μm and 0.02, respectively. For the Au-IDT/CTGS(0°, 155°, 90°) SAW resonator with λ of 32 μm, *N* of 100.5, and N_R of 50, *h* and *h*/λ were 0.30 μm and 0.009, respectively.

The electrode pads of the CTGS resonator sample mounted on a jig were Au-wire-bonded to the ends of a copper or nickel wire with a diameter of 1 mm covered with an insulating tube. The other wire ends were connected to a network analyzer.

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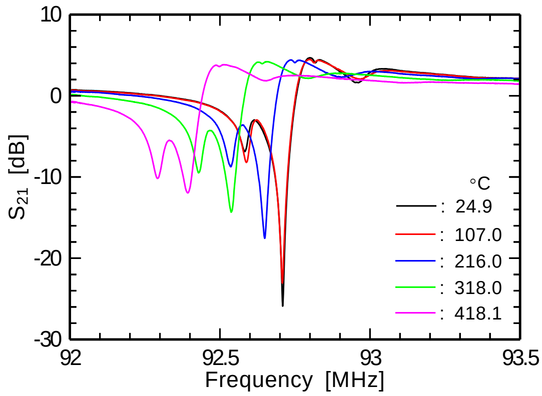

Fig. 1 Measured S_{21} properties.

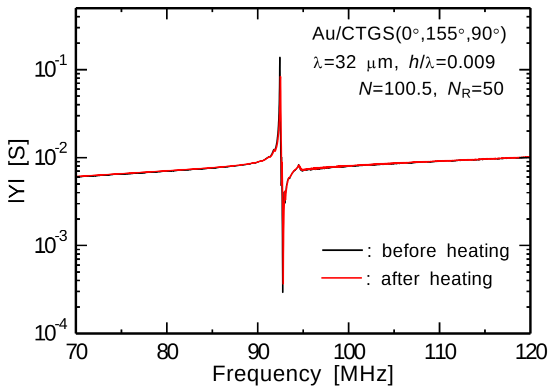

Fig. 2 Measured resonance property of SH SAW on Au/CTGS(0°, 155°, 90°) with λ=32 μm.

The sample was placed in an electric furnace, and the S_{21} transmission property between the IDTs was measured as a function of ambient temperature. **Figure 1** shows the result of measurement using a copper wire for the Au-IDT/CTGS(0°, 155°, 90°) SAW resonator. In the antiresonance frequency and response were observed to decrease as the temperature increased, then the response completely disappeared at 500°C. **Figure 2** shows the resonance property measured in a manual probe station at room temperature before and after heating up to 500°C. The resonance property after heating was slightly reduced compared with that before heating; however, it was mostly retained. Therefore, it was considered that the response decreased as the temperature increased because of the increase in resistance owing to the oxidation of the copper wire. Finally, the response disappeared owing to the complete oxidation of the copper wire. Even with the nickel wire, which is less susceptible to oxidation, a reduction in response was observed with increasing temperature, so further investigation of other factors is required to evaluate higher temperature characteristics.

Figure 3 shows the frequency shift $\Delta f/f_0$ measured from the antiresonance frequency (f_0) at 26.6°C as a function of temperature. The parabolic properties with turnover temperatures of 50°C and 320°C were observed for the Au-IDT/CTGS(0°, 155°, 90°) and Au-IDT/CTGS(0°, 134°, 90°) SAW resonators, respectively. Therefore, it was found that the temperature coefficient of frequency (TCF) at high temperatures changes depending on the cut angle of CTGS.

3. Determination of CTGS Second-Order Temperature Coefficient of Elastic Constant

The second-order temperature coefficient of the elastic constant of CTGS was calculated from the measured frequency shift. The effect of the elastic constant tensor of CTGS on the phase velocity of SH-SAW was investigated, and it was found that only c_{14} and c_{44} exert an effect; in particular, c_{44} has the greatest effect. Therefore, assuming that only c_{44} is involved in the phase velocity, the second-order temperature coefficient of c_{44} was determined by fitting the measured and theoretical values. The fitted theoretical curve for CTGS(0°, 155°, 90°) is also shown in Fig. 3. The fitting yields a second-order temperature coefficient of -222×10^{-9}/°C^2 for c_{44}, which is comparable to the second-order temperature coefficient of c_{44} for quartz (-255×10^{-9}/°C^2)[5]. The calculated curve for CTGS(0°, 134°, 90°) using the second-order temperature coefficient of c_{44} almost agreed with the measured value as shown in Fig. 3.

Figure 4 shows the calculated frequency shift of an SH-SAW on CTGS(0°, θ, 90°) with Au thin film (h/λ=0.01) up to 1,000°C, taking into account the determined second-order temperature coefficient of c_{44}. As shown in Fig. 4, the turnover temperature from room temperature to around 450°C was observed depending on the cut angle. The maximum turnover temperature was estimated to be 456°C for θ=115° while the simulated effective K^2 was 0.4%[4]. The TCF at 450°C for θ=155° was estimated to be –18.7 ppm/°C while the simulated effective K^2 was 1.22%[4]. Therefore, these results show the potential for sensor applications in such high-temperature environments.

4. Conclusions

In this study, the resonance properties of SH-SAWs on CTGS(0°, 134°, 90°) and CTGS(0°, 155°, 90°) were evaluated experimentally up to 500°C, and the second-order temperature coefficient of c_{44} of CTGS was determined by

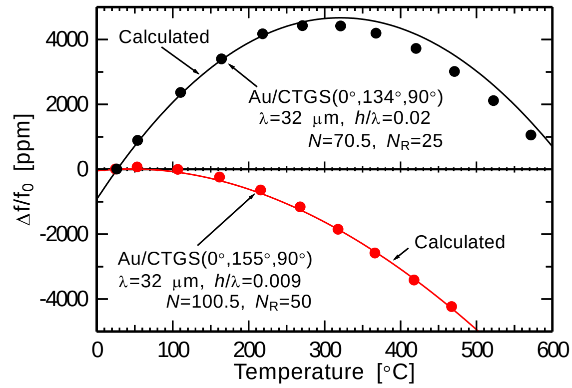

Fig. 3 Measured temperature dependence of antiresonance frequency.

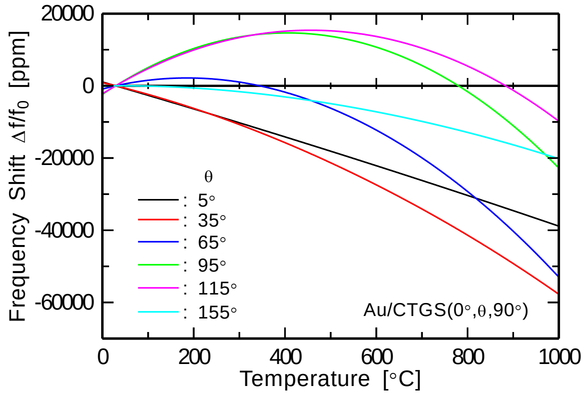

Fig. 4 Calculated frequency shift of SH-SAW on CTGS(0°, θ, 90°) with Au film.

fitting the measured and calculated frequency shifts. The parabolic properties with turnover temperatures of 50°C and 320°C were observed for CTGS(0°, 155°, 90°) and CTGS(0°, 134°, 90°), respectively.

The second-order temperature coefficient of c_{44} was estimated to be -222×10^{-9}/°C^2, which is comparable to that of quartz crystal. In the next step, the second-order temperature coefficient of elastic constant c_{14} of CTGS will also be determined.

Acknowledgments

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