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Shear-horizontal Surface Acoustic Wave on New Langasite-type Piezoelectric Single Crystal

新規ランガサイト型圧電単結晶上のラブ波型 SH 波

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1. Introduction

For next-generation mobile communication systems, high-performance surface acoustic wave (SAW) devices with a wide fractional bandwidth, a stable temperature property, low attenuation, and high frequency are required. As piezoelectric materials for SAW devices, single crystals, such as quartz, which has a small temperature coefficient of delay (TCD), and $LiNbO_3$ (LN) and $LiTaO_3$ (LT), which have large electromechanical coupling factors (K^2), have mainly been utilized. However, K^2 of quartz and TCD of LN and LT are insufficient for the required values.

Two decades before, langasite-type single crystals such as $La_3Ga_5SiO_{14}$ (LGS) and $La_3Ga_{5.5}Ta_{0.5}O_{14}$ received attention as attractive materials for devices with the Rayleigh-type SAW, because of their excellent TCD and approximately three times larger K^2 than that of quartz. However, there were problems of high cost and difficulty in controlling the composition during crystal growth. Yoshikawa *et al.* have developed a new langasite-type single-crystal $Ca_3TaGa_3Si_2O_{14}$ (CTGS) to solve these problems.[1]

On the other hand, one of the authors, Kakio, and coworkers have reported that, by loading a high-density thin film, such as a gold (Au) film or a tantalum pentoxide (Ta_2O_5) film on LGS at an Euler angle of (0°,θ,90°) for a cut angle θ between 0° and 20°, a pure shear-horizontal (SH) SAW with K^2 of approximately 1% and zero TCD can be obtained.[2-5]

In this study, the propagation and resonance properties of a SH SAW on (0°,θ,90°)-cut CTGS with Au thin film were investigated theoretically and experimentally.

2. Theoretical Calculation

The calculated K^2 and TCD of a SH SAW on (0°, θ,90°)-cut CTGS with a Au thin film as a function of the cut angle θ are shown in **Figs. 1(a) and 1(b)**, respectively. The Au film thickness normalized by the wavelength (h/λ) is used as a parameter in these figures. K^2 was obtained as $2(v_\mathrm{f}-v_\mathrm{m})/v_\mathrm{m}$, where v_f and v_m are the phase velocity of the free and metallized surfaces, respectively. For the calculation of v_f, the dielectric constant of Au film was assumed to be that in a vacuum.

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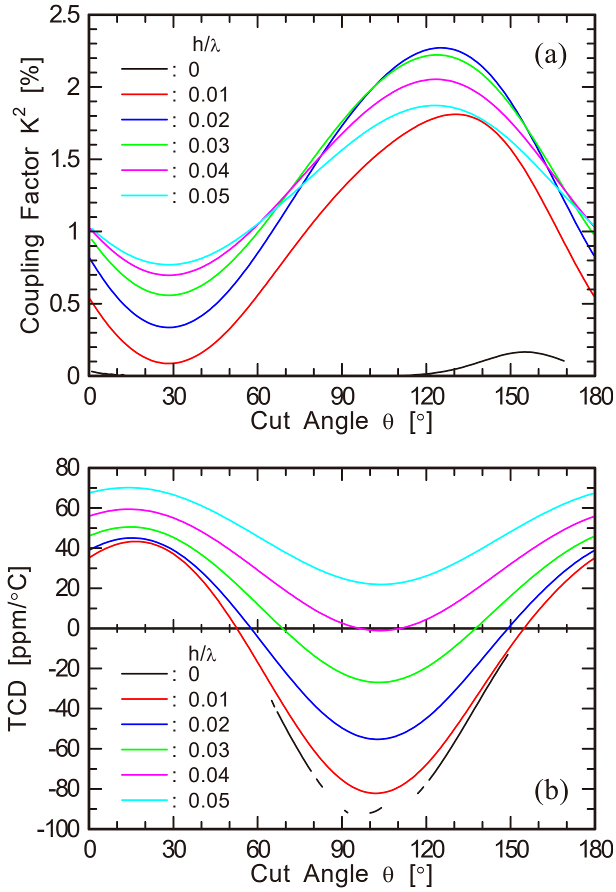

Fig. 1 Cut-angle dependences of (a) K^2 and (b) TCD for SH SAW on Au/CTGS(0°,θ,90°).

As shown in Fig. 1(a), K^2 without the Au film is below 0.2%. For all cut angles, K^2 increases considerably with film thickness and is maximum at a certain cut angle and a certain film thickness. Under the conditions of θ=125° and h/λ=0.02, the maximum K^2 of 2.27% was obtained, which is about 2.2 times larger than that of the SH SAW on Au/LGS.

As shown in Fig. 1(b), TCD without the film exhibits a negative value in the cut angle range from 50° to 155°. When the Au film is loaded, TCD increases monotonically because the Au film has a positive TCD. Therefore, zero TCD can be obtained by choosing the appropriate thickness of the Au film within the cut angle range from 50° to 155°. From a comparison with Fig. 1(a), it was found that K^2 of approximately 2.0% and a zero TCD can be obtained simultaneously by loading with a Au thin film. For instance, under the conditions of θ=134° and h/λ=0.032, K^2 of 2.13% and zero TCD were obtained simultaneously.

To investigate the cause of the enhancement of K^2, the particle displacement of SH SAW was calculated. **Figure 2** shows the SH component u_2 as a function of the normalized depth from a surface of CTGS(0°, 134°,90°) by wavelength λ. The normalized displacement by the surface value without the Au film penetrates a distance exceeding 10 wavelengths. On the other hand, the penetration depth decreases to less than a few wavelengths with increasing Au film thickness. Therefore, it was confirmed that the high coupling was achieved by the strong energy trapping in the vicinity of the surface owing the high density of the Au film.

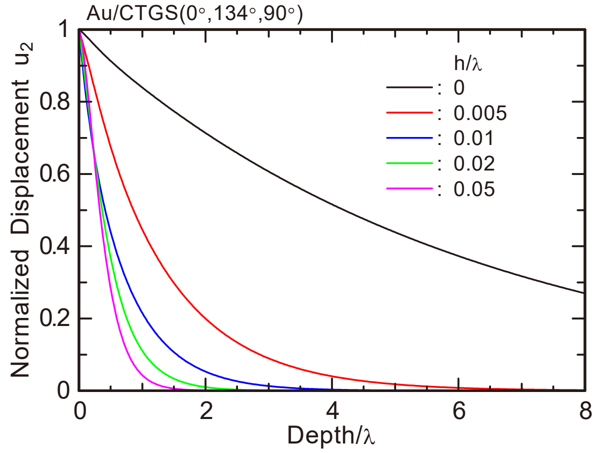

Fig. 2 Calculated normalized particle displacement u_2 as a function of the normalized depth from the surface of CTGS(0°, 134°,90°) by wavelength λ.

3. Measured Resonance Property

On the basis of the above theoretical calculations, a sample of Au/CTGS SAW resonator was fabricated and its resonance properties were evaluated. A CTGS substrate with θ=134° was prepared and a Au thin film with a film-thickness of 670 nm (h/λ=0.02) including a 10-nm-thick Cr adhesion layer was deposited on the substrate by RF-sputtering. An IDT-type resonator pattern with λ=32 μm, an aperture width of 25 λ, finger pairs of N=100.5, and N_R=25 reflectors was fabricated.

Figure 3 shows the resonance property of the SH SAW resonator on the Au/CTGS(0°,134°,90°) sample measured using a network analyzer. The response of the SH SAW is observed clearly at around 86 MHz. The response at around 94 MHz is considered to be due to a bulk wave. The strong response of the SH SAW with an admittance ratio of 39 dB and resonance Q of 3,440 is obtained. However, the measured fractional bandwidth of 0.27% is smaller than the expected value, which is half the value of the corresponding K^2.

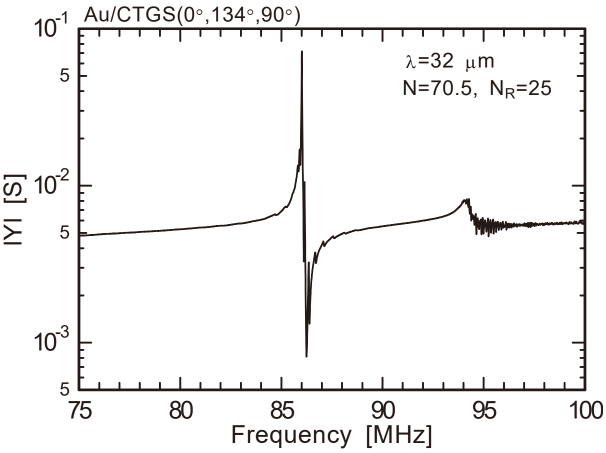

Fig. 3 Measured resonance property of SH SAW on Au/CTGS(0°,134°,90°) with λ=32 μm.

4. Conclusions

In this study, the propagation and resonance properties of a SH SAW on (0°,θ,90°)-cut CTGS with a Au thin film were investigated theoretically and experimentally.

First, from the theoretical calculation, it was found that K^2 of approximately 2.0% and a zero TCD can be obtained simultaneously at a certain cut angle and a certain thickness of a loaded Au thin film. Then, an SAW resonator was fabricated on Au/CTGS(0°,134°,90°) and a strong resonance property of the SH SAW was obtained. However, the fractional bandwidth was smaller than the expected value. In the next step, we will evaluate the temperature property and investigate the cause of the small fractional bandwidth.

Acknowledgment

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