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Resonance Property of 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 波の共振特性

Ryoto Suzuki[1‡], Masashi Suzuki[1], Shoji Kakio[1], and Noritoshi Kimura[2]
([1]Univ. of Yamanashi; [2]Piezo Studio Inc.)
鈴木 涼人 [1‡]，鈴木 雅視 [1]，垣尾 省司 [1]， 木村 悟利 [2] ([1]山梨大学, [2]Piezo Studio)

1. Introduction

For the rapid development of mobile communication systems, high-performance surface acoustic wave (SAW) devices are required. As piezoelectric materials for SAW devices, $LiNbO_3$ (LN), $LiTaO_3$ (LT), and quartz have mainly been utilized. Although LN and LT have a large electromechanical coupling factor (K^2), their temperature coefficients of frequency (TCFs) are also large. In contrast, quartz has small K^2 and TCF. Therefore, the TCFs of LN and LT, and the K^2 of quartz are insufficient for the required values.

Langasite-type piezoelectric single crystals such as $La_3Ga_5SiO_{14}$ (LGS) and $La_3Ga_{5.5}Ta_{0.5}O_{14}$, have zero TCF and approximately threefold larger K^2 than quartz, and they have received attention as attractive materials for devices with the Rayleigh-type SAW (R-SAW). However, they have problems such as high cost and difficulty in controlling their composition during crystal growth.

Yoshikawa *et al*. have solved these problems by developing a new langasite-type single-crystal $Ca_3TaGa_3Si_2O_{14}$ (CTGS).[1] One of the authers, Kakio and colleagues have reported that a shear-horizontal (SH) wave with K^2 of approximately 1% and zero TCF can be obtaind by forming an interdigital transduser (IDT) using high-density thin films such as gold (Au).[2–5] In a previous report, we theoretically found that SH SAW with K^2 of approximately 2.0%, and zero TCF can be obtained on CTGS at a Euler angle of (0°,134°,90°) by utilizing Au-IDT.[6] In this study, the resonance properties including TCF of a SH SAW on (0°,134°,90°)-cut CTGS with Au-IDT and Al-IDT were evaluated experimentally.

2. Measurement of resonance property

A sample of an Al-IDT/(0°,134°,90°)CTGS SAW resonator was fabricated and its resonance properties were evaluated. An Al thin film of 0.35 μm thickness was deposited on the substrate, and an IDT-type resonator pattern with a wavelength λ of 6.4 μm, an aperture width *W* of 50λ, finger pairs *N* of 100.5, and a reflector number N_R of 100 was fabricated. The Al film thickness normalized by the wavelength (h/λ) was 0.055.

g21te013@yamanashi.ac.jp

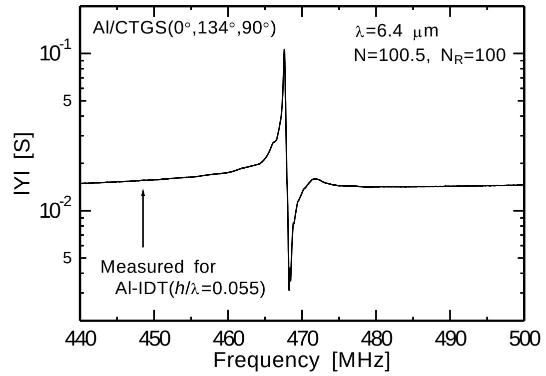

Fig. 1 Measured resonance property of SH SAW on Al/CTGS(0°,134°,90) with λ=6.4 μm.

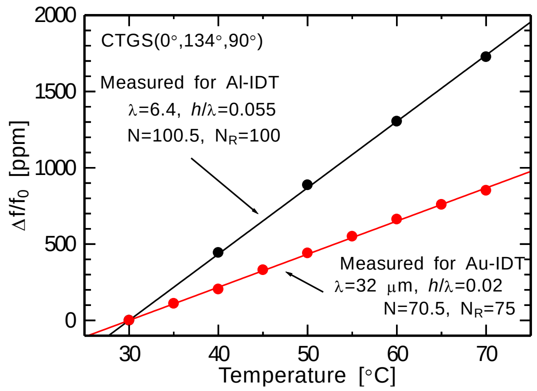

Fig. 2 Measured temperature dependences of resonance frequency.

Figure 1 shows the resonance property of the SH SAW resonator on the Al-IDT/CTGS(0°,134°,90°) sample measured using a network analyzer. The response of the SH SAW is clearly observed at approximately 468 MHz. The response of the SH SAW with an admittance ratio of 30.6 dB and resonance *Q* of 2,230 is obtained. This resonance property is smaller then that of Au/CTGS(0°,134°,90) with λ=32 μm and h/λ=0.02 (admittance ratio of 38.9 dB, resonance *Q* of 3,440).[6] However, this measurement result shows that the energy trapping of SH SAW in the vicinity of the surface can be achieved by using Al-IDT.

The TCFs of the Al-IDT sample and the previous Au-IDT sample were measured from the resonance frequency measured at 30°C as a reference (f_0) and every 10°C until 70°C. **Figure 2** shows the measured frequency shift $\Delta f/f_0$ as a function of temperature. The TCF was determined from the linearly fitted slope. **Figure 3** shows the calculated TCF of a SH SAW on CTGS(0°,θ,90°) with a Au thin film as a function of the cut angle θ. The measured TCFs are plotted in Fig. 3. The calculated parameters is h/λ of uniformly loaded Au film thickness. The measured TCF of Au-IDT (21.5 ppm/°C) is consistent with the calculated value, and that of Al-IDT (43.5 ppm/°C) is consistent with the calculated value for a small Au thickness. Therefore, it can be expected that zero TCF is achieved by adjusting the film thickness of Au-IDT for θ=134° or by choosing θ of approximately 155° even with Al-IDT.

3. Simulation of resonance property

Mechanical loss was determined by fitting the measured resonance property for Al-IDT/CTGS(0°,134°,90) and the simulated one by the finite elements method (FEM) under the same conditions as those in the measurement. Results showed that CTGS had a mechanical loss of $1/Q_m$=0.00048. In this fitting, when the simulated resonance frequency matched the measured value, the Al electrode thickness was determined to be 0.042 λ, which is smaller than the experimantal value. This can be attributed to over–etching.

The effective coupling factor (K^2_{eff}) was obtained from the measured resonance and anti–resonance frequencies. For an infinitely periodic IDT with cut angles θ of 134° and 155°, the resonance properties were simulated and compared with the measured K^2_{eff}. **Figure 4** shows both measured and simulated values of K^2_{eff} as a function of the normalized electrode thickness. For the simulated values, for both IDTs, CTGS(0°,155°,90°) exhibits a higher K^2_{eff} than CTGS(0°,134°,90°). Moreover, it was theoretically clarified that K^2_{eff} similar to that of Au-IDT can be obtained by using Al-IDT when h/λ of Al film thickness is larger than 0.1. The maximum K^2_{eff} value for Al- and Au-IDTs were simulated to be 1.22% at h/λ=0.10 and K^2_{eff} =1.24% at h/λ=0.015, respectively. However, the measured K^2_{eff} values for both IDTs were 50–60% of the simulated values. This could be due to the insufficient number of finger pairs or reflectors.

4. Conclusions

In this study, the resonance properties of a SH SAW on (0°,134°,90°)-cut CTGS with Au or Al thin film were investigated theoretically and experimantally. A SAW resonator was fabricated on Al/CTGS(0°,134°,90°) and the resonance property of the SH SAW were evaluated. The measured result shows that the energy trapping of SH SAW in the vicinity of the surface can be achieved by using Al-IDT. The measured TCFs of Au-IDT and Al-IDT

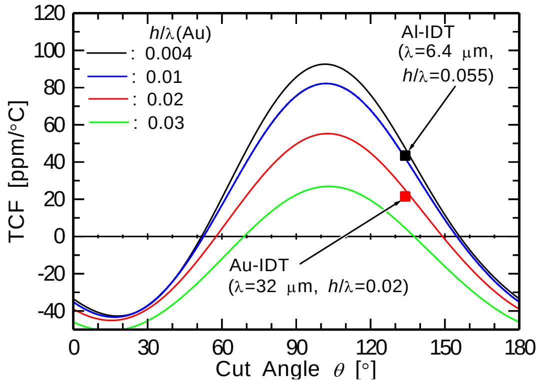

Fig. 3 Cut-angle dependence of TCF for SH SAW on Au/CTGS(0°,θ,90°).

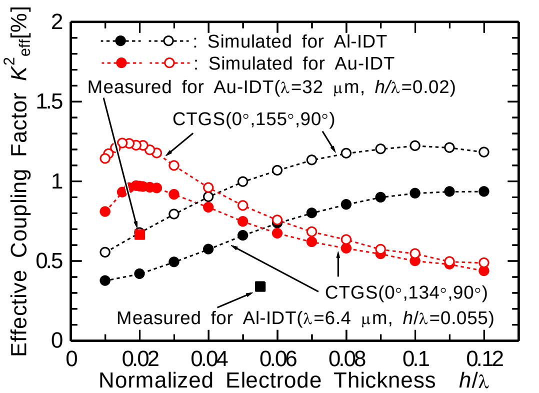

Fig. 4 Normalized electrode thickness dependence of K^2_{eff}.

are consistent with the calcurated values, and that both IDTs achieved zero TCF. The maximum K^2_{eff} value were found to be more than 1.2% of the simulated values. However, the measured K^2_{eff} value for both IDTs were 50–60% of the simulated values. In the next step, we will investigate experimentally the resonance properties of Al/(0°,155°,90°)CTGS.

Acknowledgment

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