Shear-Horizontal Surface Acoustic Wave on $Ca_3TaGa_3Si_2O_{14}$ Piezoelectric Single Crystal

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***Summary*— In this study, the propagation and resonance properties of shear-horizontal surface acoustic waves (SH SAWs) on a rotated Y-cut 90°X propagating $Ca_3TaGa_3Si_2O_{14}$ (CTGS) with a Au- or Al-interdigital transducer (IDT) were investigated theoretically and experimentally. It was found that not only a high-density Au-IDT but also a conventional Al-IDT enables the energy trapping of SH SAW in the vicinity of the surface. For both IDTs, the effective electromechanical coupling factor of about 1.2% and the zero temperature coefficient of frequency can be simultaneously obtained by adjusting the cut angle of CTGS and the electrode film thickness.**

***Keywords*— $Ca_3TaGa_3Si_2O_{14}$; shear-horizontal surface acoustic wave; zero temperature coefficient of frequency**

I. Introduction

With the rapid development of mobile communication systems in recent years, high-performance surface acoustic wave (SAW) devices are required. Two decades before, langasite-type single crystals such as $La_3Ga_5SiO_{14}$ (LGS) received attention as attractive materials for devices with the Rayleigh-type SAW, because of their excellent temperature coefficients of frequency (TCFs) and approximately three times larger electromechanical coupling factor K^2 than that of quartz. However, they have problems such as high cost and difficulty in controlling their composition during crystal growth. To solve these problems, a new class of ordered langasite structure single-crystals such as $Ca_3TaGa_3Si_2O_{14}$ (CTGS) have been developed [1]. On the other hand, Kakio *et al.* have reported that a shear-horizontal (SH) SAW with K^2 of approximately 1% and zero TCF can be obtained by forming an interdigital transducer (IDT) using high-density thin films such as gold (Au) on a rotated Y-cut 90°X propagating LGS [Euler angle: (0°,θ,90°)] [2].

Here, we show the propagation and resonance properties of the SH SAW on CTGS(0°,θ,90°) with Au- or Al-IDT, which were investigated theoretically and experimentally.

II. Calculated Propagation Properties

We analyzed the propagation properties of SH SAW on the layered structure of air/Au or Al film/CTGS(0°,θ,90°) using Farnell and Adler's method [3]. The material constants of CTGS reported by Ohashi *et al*. were used [4,5]. Figure 1 shows the calculated TCF with Al film as a function of the cut angle θ. The Al film thickness h normalized by the wavelength λ is used as a parameter. The measured values of TCF described later are also shown in Fig. 1.

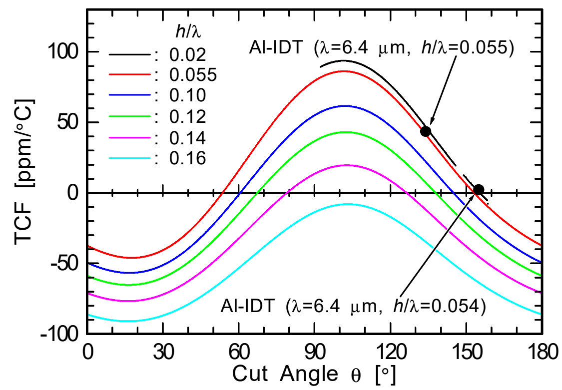

Fig. 1. TCF of SH-SAW on CTGS(0°,θ,90°) with Al film.

CTGS has cut angle ranges that exhibit positive and negative TCFs. The TCF shifts to a negative value when the Au or Al film is loaded because Au and Al have negative TCFs. Therefore, zero TCF can be obtained by adjusting the appropriate thickness of the Au or Al film within the cut angle from 50° to 155°. The calculated K^2 increases with film thickness for all cut angles and is maximum at a certain cut angle and a certain film thickness. The maximum K^2 for the Au film was calculated to be 2.3% at h/λ=0.02 and θ=125°.

III. Measured Resonance Properties

IDT-type resonator patterns with reflectors were fabricated on CTGS(0°,134° or 155°,90°) using a vacuum-evaporated Al film or Au film with a 40-nm-thick Cr adhesion layer deposited by RF sputtering. Figure 2 shows the measured resonance property of the SH SAW on the Al-IDT/CTGS(0°,134° or 155°,90°) sample with λ of 6.4 μm, finger pairs N of 100.5, number of reflectors N_R of 100, an aperture width W of 50λ, and h/λ of 0.054–0.055 using a network analyzer.

The response of the SH SAW is observed clearly at around 467 MHz for both cases. The response was larger for θ=155° than for θ=134°, and an admittance ratio (AR) of 44.7 dB and resonance Q (Q_r) of 2,340 were observed. For the Au-IDT/CTGS(0°,155°,90°) sample with λ=32 μm, N=70.5, N_R=100, W=25λ, and h/λ=0.02, AR of 53.0 dB and Q_r of 3,080 were obtained. These measurement results show that the energy trapping of SH SAW in the vicinity of the surface can be

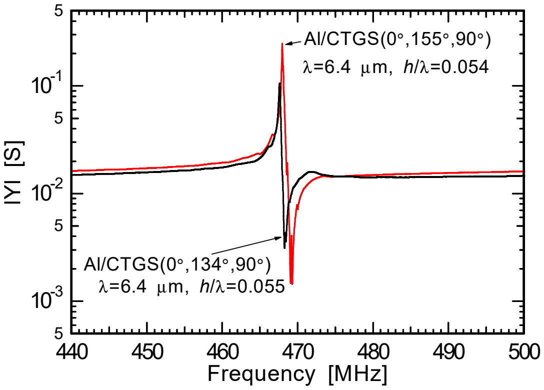

Fig. 2. Measured resonance property of SH SAW on Al-IDT/CTGS(0°,134° or 155°,90°) with λ=6.4 μm.

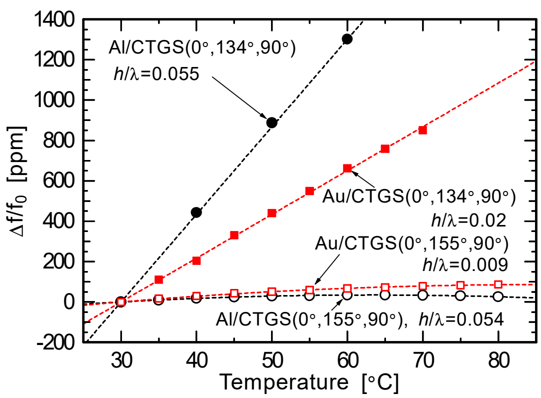

Fig. 3. Measured temperature dependence of resonance frequency.

achieved by using not only a high-density Au-IDT but also a conventional Al-IDT.

Figure 3 shows the frequency shift $\Delta f/f_0$ measured from the resonance frequency (f_0) at 30°C as a function of temperature. The TCF was determined from the first-order coefficients of the fitted curves. The measured TCFs for Al-IDT were 43.5 and 1.8 ppm/°C for θ=134° and 155°, respectively, and the results agreed with the calculated values as shown in Fig. 1. For Au-IDT, the measured TCFs were 21.5 and 3.1 ppm/°C for θ=134° and 155°, respectively.

IV. Simulated Effective Coupling Factor

The effective coupling factor (K^2_{eff}) was obtained from the measured resonance and anti-resonance frequencies. Using a simulation model consisting of an infinitely periodic IDT on CTGS(0°,134° or 155°,90°), we simulated the resonance properties by a finite element method 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. As the simulated result, for both IDTs, CTGS(0°,155°,90°) exhibits a higher K^2_{eff} than CTGS(0°,134°,90°). The maximum simulated values of K^2_{eff} for Al- and Au-IDTs were 1.22% at h/λ=0.10 and 1.24% at h/λ=0.015, respectively. It was found that K^2_{eff} similar to that of Au-IDT could be obtained using Al-IDT. However,

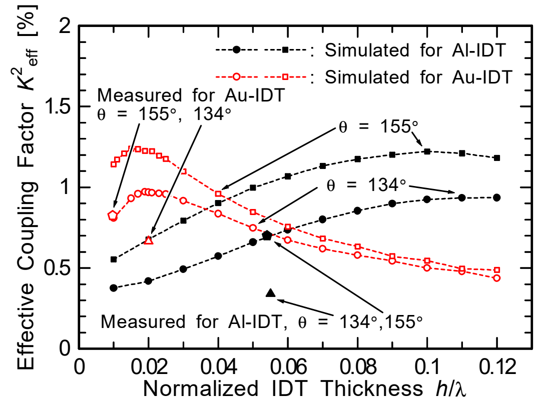

Fig. 4. Normalized electrode thickness dependence of K^2_{eff}.

the measured values of K^2_{eff} for both IDTs were 50–70% of simulated values. This could be due to the insufficient number of finger pairs or reflectors and narrow electrode finger widths that contribute to energy concentration by over-etching.

V. Conclusions

In this study, the propagation and resonance properties of SH SAW on CTGS(0°,θ,90°) with Au- or Al-IDT were investigated theoretically and experimentally. First, from the theoretical calculation, it was found that a zero TCF can be obtained at a certain cut angle and a certain thickness of a loaded Au or Al thin film. Then, SAW resonators were fabricated on CTGS(0°,134° or 155°,90°) using Au- or Al-IDT, and strong resonance properties and near-zero TCF of the SH SAW were measured at a certain electrode film thickness. From the measured and simulated results, K^2_{eff} of approximately 1.2% and zero TCF can be simultaneously obtained by using not only a high-density Au-IDT but also a conventional Al-IDT and by adjusting the cut angle of CTGS and the electrode film thickness. In the next step, we will establish the conditions under which zero TCF can be obtained at room temperature.

Acnowledgment

This research was supported by the Adaptable and Seamless Technology Transfer Program through Target-driven R&D (A-STEP) from the Japan Science and Technology Agency (JST) under Grant Number JPMJTM20NL.

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