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Analysis of Leaky Surface Acoustic Waves on Similar-Material Bonded Structure

同種材料接合構造におけるリーキーSAW の解析

Takumi Fujimaki‡, Masashi Suzuki, and Shoji Kakio (Univ. of Yamanashi)
藤巻 貴海‡，鈴木 雅視，垣尾 省司（山梨大）

1. Introduction

High-performance surface acoustic wave (SAW) filters with a high coupling factor, high *Q* factor, and high stability are required for next-generation communication systems. However, when using a single piezoelectric substrate such as $LiTaO_3$ (LT) or $LiNbO_3$ (LN), it is difficult to satisfy these requirements simultaneously. Recently, dissimilar-material bonded structures have attracted attention. In our research group, using a bonded structure comprising an LT or LN thin plate thinner than one wavelength and a quartz support substrate, we theoretically and experimentally clarified that a high coupling factor, low attenuation, and high stability can be realized simultaneously for both a shear horizontal leaky SAW (LSAW) and a longitudinal LSAW.[1,2] Among these performance enhancements, a high coupling factor and low attenuation were achieved mainly by the concentration of particle displacements in the vicinity of the surface owing to the difference in the phase velocity between the thin plate and the support substrate. High stability was achieved by the cancellation of the temperature coefficients of the thin plate and quartz.

One of the problems in dissimilar-material bonding is the difficulty of the bonding process because of the difference between the thermal expansion coefficients of the materials. By utilizing the elastic anisotropy of LT and LN, control of SAW propagation properties, that is, a high coupling factor and low attenuation but nor high stability, can be expected by using a similar-material bonded structure.

In this study, LSAW propagation and resonance properties on a bonded structure comprising an LN thin plate and an LN support substrate were investigated theoretically.

2. Theoretical Calculation

10°Y-cut X-propagation LN (10°YX-LN) having a large electromechanical coupling factor (K^2) was chosen as the thin plate, and the rotated Y-cut X-propagation LN (Rot. YX-LN) was used as the support substrate. LSAW propagation properties on the bonded structure were calculated. The material constants of LN reported by Kushibiki *et al.* were used. **Figures 1(a)** and **1(b)** show the attenuation as a function of the cut angle from the Y-axis of the support LN substrate for the free and metallized surfaces, respectively. The parameter is the thin-plate thickness in the range from 0.05λ to 0.75λ (λ: wavelength).

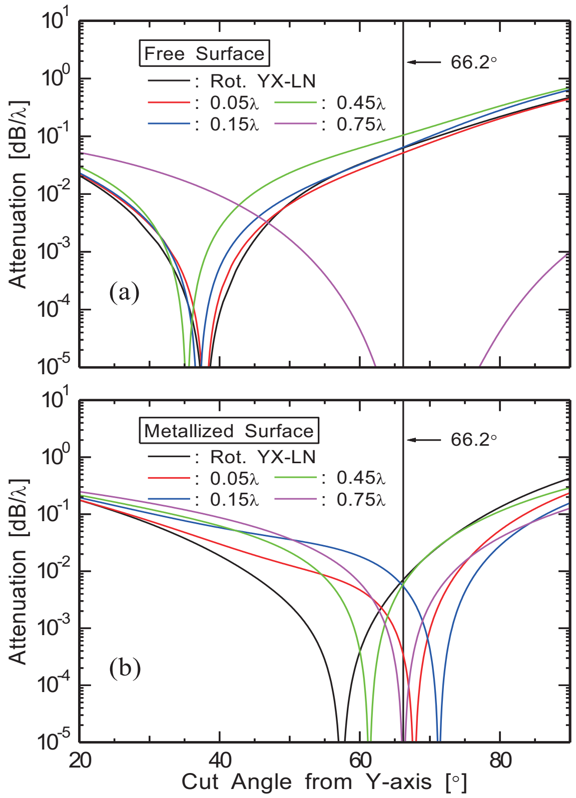

Fig. 1 Attenuation of LSAW on 10°YX-LN/Rot. YX-LN for (a) free and (b) metallized surfaces.

For the free surface, the cut angle at which attenuation is zero shifted slightly in the negative direction from 38° in the single LN with increasing thin-plate thickness, then started to shift in the positive direction at a thin-plate thickness of 0.45λ. Moreover, it shifted to around 66° at 0.75λ.

On the other hand, for the metallized surface, the cut angle at which attenuation is zero shifted to 71° from 57° in the single LN at 0.15λ, then shifted in the negative direction to 61°. Moreover, it again shifted in the positive direction at 0.45λ, reaching 66.2° at 0.75λ. From the above characteristics, it was found that 10°YX-LN(0.75λ)/66.2°YX-LN shows zero attenuation on the free and metallized surfaces

g19te017@yamanashi.ac.jp

simultaneously. Moreover, K^2 of the bonded structure was 19.2% and close to K^2 of 10°YX-LN (21.5%). As a result, when an LN thin plate with a cut angle ranging from -10° to 50° is bonded to a Rot. YX-LN support substrate, there is a condition under which attenuation is zero on the free and metallized surfaces simultaneously.

3. Finite Element Method (FEM) Analysis

Using a FEM system, the admittance properties of an LSAW in the case of forming an infinite periodic interdigital transducer (IDT) with a period λ of 8.0 μm and thin-film thickness of 0.4 μm (0.05λ) were analyzed. A perfect matching layer was provided at the bottom of the support substrate with a 10λ thickness. The mechanical loss Q_m of LN was assumed to be free or 1,000, and dielectric loss was not taken consideration. **Figure 2(a)** shows the resonance properties of single 10°YX-LN and 66°YX-LN structures. The single 10°YX-LN has a high resonance Q_r of 490,000 for the free Q_m and a wide fractional bandwidth of 13.7%, however, the anti-resonance Q_a was low (100) even for the free Q_m. The single 66°YX-LN has low values of both Q_r and Q_a of 700 and 900, respectively, even for the free Q_m, and a fractional bandwidth of 5.5% narrower than that of 10°YX-LN.

On the other hand, as shown in **Fig. 2(b)**, for the bonded structure of 10°YX-LN(0.65λ)/66°YX-LN, high values of both Q_r and Q_a of 490,000 and 90,000, respectively, were obtained. The thin-plate thickness was adjusted from 0.75λ, at which attenuation was zero in the analytical solution, to 0.65λ because of the effect of the Al electrode. In addition, the fractional bandwidth of this bonded structure was 12.2% and close to that of 10°YX-LN.

When Q_m was taken into consideration, Q_r and Q_a for the single 10°YX-LN were 1,140 and 100, respectively. For 10°YX-LN(0.75λ)/66°YX-LN, Q_r and Q_a were 1,150 and 1,570, respectively. Moreover, the admittance ratio of the bonded structure was 99 dB even considering mechanical loss, and higher than that on the simple structure. The above analyzed resonance properties are summarized in **Table I**. From these results, it was found that, by utilizing the similar-material bonded structure, better resonance properties than those on a single substrate can be obtained.

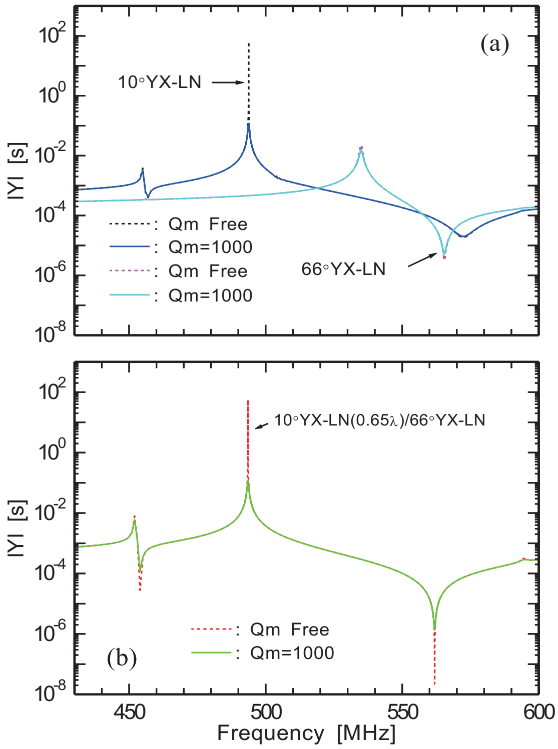

Fig. 2 Simulated admittance properties of LSAW on (a) single 10° or 66.2°YX-LN and (b) 10°YX-LN/66.2°YX-LN.

4. Conclusion

In this study, we theoretically investigated the propagation and resonance properties of an LSAW on a bonded structure comprising an LN thin plate and an LN support substrate with different cut angles. It was found that, by utilizing the similar-material bonded structure, zero attenuation can be obtained for the free and metallized surfaces simultaneously, and better resonance properties than those on a single substrate can be obtained. As the next step, we will investigate such bonded structures experimentally.

References

1. M. Gomi, *et al.*: Jpn. J. Appl. Phys. **56** (2017) 07JD13.
2. J. Hayashi, *et al.*: Jpn. J. Appl. Phys. **57** (2018) 07LD21.

Table I Resonance properties of LSAW.

Substrate structure	Q_m	Admittance ratio [dB]	Fractional bandwidth [%]	Q_r	Q_a
10°YX-LN	Free	131	13.7	493,800	100
	1000	75	13.7	1,140	100
66°YX-LN	Free	77	5.4	700	900
	1000	69	5.4	450	570
10°YX-LN(0.65λ) /66°YX-LN	Free	188	12.2	493,500	93,600
	1,000	99	12.2	1,150	1,570