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Resonance analysis of longitudinal leaky SAW third harmonic on bonded $LiNbO_3$/quartz structure

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1. Introduction

Surface acoustic wave (SAW) resonators with high frequency, wide bandwidth, large Q factor, and small temperature coefficient of frequency (TCF) are required for high-performance SAW devices. The utilization of propagation modes with a high phase velocity and higher-order SAW harmonics has been proposed as an approach to achieve high-frequency operation. Longitudinal leaky SAWs (LLSAWs) exhibit a higher phase velocity than do the Rayleigh-type SAWs (R-SAWs) and leaky SAWs (LSAWs) used in conventional SAW devices. However, LLSAWs leak more energy into the substrate as compared with LSAWs and therefore exhibit significant attenuation. Moreover, SAW harmonics are the odd-order components of SAWs excited by interdigital transducers (IDTs), excluding fundamental waves. The excitation intensity depends on the ratio of the electrode width a to the pitch p (metallization ratio: a/p) of the IDT.[1)]

Previously, our research group reported that the resonance Q factor of LLSAWs increases because the energy leakage into the substrate significantly decreases when a $LiTaO_3$ (LT) or $LiNbO_3$ (LN) thin plate is bonded to a quartz (Qz) support substrate with a higher phase velocity than that of the thin plate.[2)] In addition, we experimentally demonstrated the enhancement of the excitation of the LSAW third harmonic by utilizing an LT/Qz bonded structure.[3)] In the previous report, we experimentally demonstrated that the LSAW fundamental wave and the third and fifth harmonics are more strongly excited on 36°YX-LN/AT90°X-Qz than on a single 36°YX-LN, and the fractional bandwidth (*FBW*) of the third harmonic (2.8%) is twice that of 36°YX-LT/AT0°X-Qz.[4)]

In this study, to obtain higher operating frequency, we investigated theoretically the resonance properties of the third harmonic of LLSAW on an LN/Qz structure.

2. Resonance properties of LLSAWs

We used an X-cut 36°Y-propagating LN (X36°Y-LN) as the thin plate and X35°Y-Qz as the support substrate to enhance LLSAW excitation. **Figure 1** presents an overview of the finite element method (FEM) analytical model with an infinitely periodic structure. The gap of the IDT was set to 0.3 μm, which is the typical limit for SAW device manufacturing. Further, the wavelength λ was set to 3 μm, as obtained on the basis of setting a/p=0.8 for strong excitation of the third harmonic. Meanwhile, a/p=0.5 was set for the fundamental wave. A response at 6.6 GHz is expected for the third harmonic with λ=3 μm. To obtain steep responses, the normalized thin-plate thicknesses h_{Al}/λ=0.03 and h_{LN}/λ=0.08 were set for the fundamental wave. Further, h_{Al}/λ=0.01 and h_{LN}/λ=0.027, which are approximately one-third of those for the fundamental wave, were set for the third harmonic. The material Q (Q_m) of LN was assumed to be 1,000.

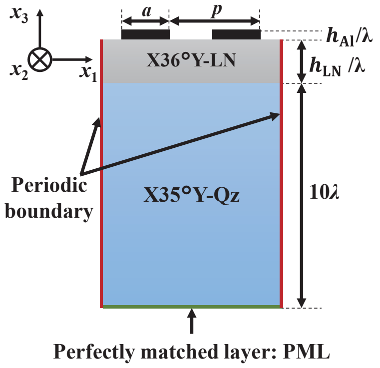

Fig. 1 Model constructed for FEM analysis.

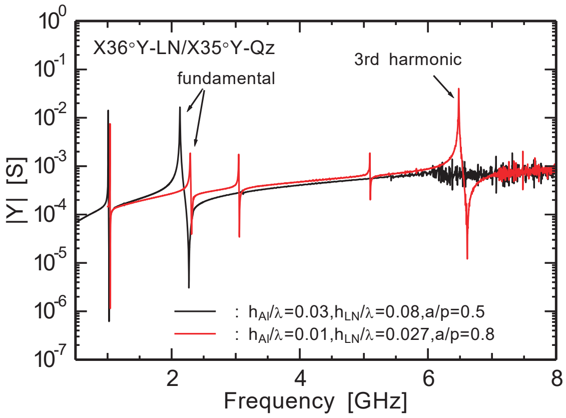

Fig. 2 Simulated LLSAW admittance properties on X36°Y-LN/X35°Y-Qz.

Figure 2 shows the simulated admittance properties of the LLSAW fundamental wave and third harmonic on X36°Y-LN/X35°Y-Qz under optimal conditions. The responses at 2–2.5 and 6–7 GHz are the fundamental waves and third harmonics,

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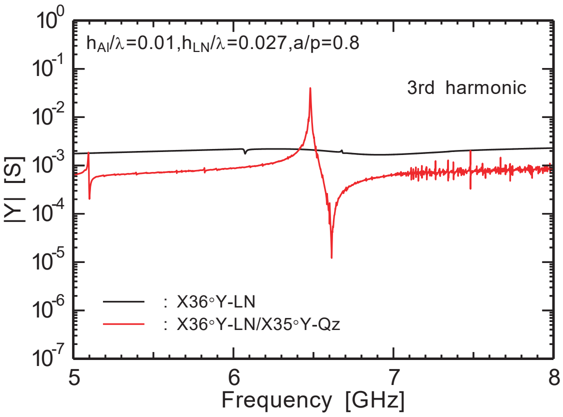

Fig. 3 Simulated admittance properties of LLSAW third harmonic on single LN and LN/Qz.

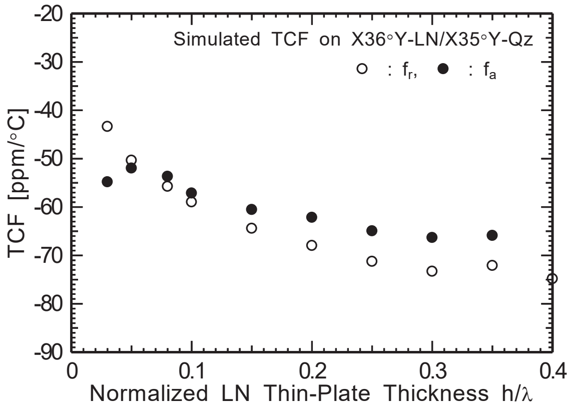

Fig. 4 Simulated TCF of fundamental LLSAW.

respectively. It is theoretically shown that the LSAW third harmonic on 36°YX-LN/AT90°X-Qz for the same wavelength has a response at 4.0 GHz, while the LLSAW third harmonic response is obtained at 6.5 GHz—approximately 1.6 times higher. The simulated admittance ratio (*AR*), *FBW*, resonance *Q* factor (Q_r), and anti-resonance *Q* factor (Q_a) of the fundamental wave on LN/Qz at a/p=0.5 were 74.1 dB, 6.1%, 470, and 760, respectively, whereas these values for the simulated fundamental wave at a/p=0.8 were 33.5 dB, 0.8%, 330, and 580, respectively.

Figure 3 shows a magnified view of the third harmonic admittance properties of the single X36°Y-LN and LN/Qz structures. The simulated *AR*, *FBW*, Q_r, and Q_a of the third harmonic on LN/Qz were 70.4 dB, 2.0%, 1,620, and 2,200, respectively, whereas no third harmonic response was obtained for the single LN.

3. Temperature coefficient of frequency

FEM was used to analyze the dependence of the TCF on the normalized LN thin-plate thickness for the fundamental LLSAW on the X36°Y-LN/X35°Y-Qz bonded structure. The expansions of Al, LN, and Qz were considered when the temperature was virtually increased from 30 °C to 80 °C, using 30 °C as the reference temperature. The simulated TCF values were obtained from the rates of change in the LLSAW fundamental wave resonance frequency (f_r) and anti-resonance frequency (f_a) with increasing temperature.

Figure 4 depicts the simulated TCF values of the LLSAW fundamental wave as functions of the normalized LN thin-plate thickness h_{LN}/λ. The TCF for the fundamental wave under optimal conditions (h_{Al}/λ=0.03, h_{LN}/λ=0.08, and a/p=0.5) is –55.7 ppm/°C for f_r, while it is –53.7 ppm/°C for f_a. These TCF values have larger absolute values than those of conventional SAW devices using a single 42°YX-LT (between–40 and –30 ppm/°C). Even for equal h_{LN}/λ, the TCF values for the third harmonic have larger absolute values than those for the fundamental wave.[3,4] Therefore, it is necessary to explore conditions conducive for more favorable TCF values.

4. Conclusion

In this study, the resonance properties of the third harmonic of LLSAW in an LN/Qz bonded structure were theoretically investigated. It was theoretically clarified that the LLSAW third harmonic on the X36°Y-LN/X35°Y-Qz bonded structure with h_{Al}/λ=0.01, h_{LN}/λ=0.027, and a/p=0.8 shows a large and steep resonance response, whereas no third harmonic response was obtained for the single LN.

The LSAW third harmonic of 36°YX-LN/AT90°X-Qz at the same wavelength has a response at 4.0 GHz, whereas the LLSAW third harmonic response was theoretically obtained at 6.5 GHz, which is approximately 1.6 times higher. However, the *FBW* was limited to 2.0%. A hybrid filter that combines a steep LLSAW filter and a wide-bandwidth filter, such as an LC filter, is expected. The TCF values of the LLSAW fundamental wave had larger absolute values than that of a typical SAW device. Since the TCF of higher harmonics tends to be worse than that of the fundamental wave, it is necessary to determine the conditions that facilitate better TCF values.

Acknowledgment

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