Decreased Nonlinear Harmonic Generation in Longitudinal Leaky SAW Resonators Based on YZ-cut $LiNbO_3$ Substrate

Xiangnan Pang[1],Yook-Kong Yong[1]
[1] Rutgers University Piscataway, NJ, USA,
Email: xiangnan.pang@rutgers.edu, yyong@soe.rutgers.edu

***Abstract*—The second (H2) and third (H3) harmonic generations in surface acoustic wave (SAW) resonators based on the YZ-cut $LiNbO_3$ operating in both longitudinal leaky SAW (LLSAW) mode and Rayleigh SAW mode were investigated and compared. For the Rayleigh SAW mode, the patterns and trends of nonlinearly excited harmonics in the YZ-cut $LiNbO_3$ were the same as those of 128° YX $LiNbO_3$ except that the peaks of nonlinear harmonic responses in YZ-cut $LiNbO_3$ were denser than the latter. However, for the YZ-cut $LiNbO_3$ LLSAW resonators, the peaks of the nonlinear harmonic responses would be 20 to 30 dBm lower than those in the Rayleigh SAW resonators. For the YZ-cut $LiNbO_3$ LLSAW resonators, we found that the quasi-periodic peaks in the nonlinear harmonics response would disappear at a substrate thickness of 500 µm. Results showed that the nonlinear harmonic generation concerns in SAW filters and duplexers may be substantially reduced by the use of longitudinal leaky SAW based on YZ-cut $LiNbO_3$.**

Keywords—Nonlinear harmonic generations, Longitudinal Leaky SAW, Acoustic Resonators, YZ-cut $LiNbO_3$

I. Introduction

Due to increased power handling and reduced size of SAW devices, the nonlinear characteristics of these devices must also be accounted for along with their linear characteristics. The nonlinear harmonic generations (H2 and H3) are due to large amplitude acoustic waves excited in slightly nonlinear materials that included the piezoelectric substrate and electrodes. Signal energy will leak into other bands and there will be an interference between the intended bands. Previous work by Marc [1] showed that the harmonics in temperature-compensated SAW based on 128° YX $LiNbO_3$ was due to the bulk wave generated in the SAW resonator substrate. The modeling method and simulation of these harmonics were performed using a formulation of coupled piezoelectric equations in the frequency domain.

In this paper the nonlinear harmonic generations in SAW resonators based on substrate YZ-cut $LiNbO_3$ were investigated. The YZ-cut $LiNbO_3$ substrate can support two types of surface waves, namely the Rayleigh SAW and LLSAW at different frequencies. The nonlinear harmonics due to the LLSAW mode were compared with the nonlinear harmonics due to Rayleigh SAW mode based on both the YZ-cut $LiNbO_3$ and 128° YX $LiNbO_3$.

II. Methods/Results

A. Modeling Method

The longitudinal leaky surface acoustic wave resonator on YZ-cut $LiNbO_3$ offered a good choice for high-frequency wide-band filters featuring strong coupling, high velocity and low losses. The structural parameters of the resonators were modeled from those in test resonators reported by Holmgren [4].

The coupled piezoelectric field equations for modeling harmonic generation effects of SAW and BAW resonators were derived in our previous work [2], [3]. The equations could be implemented using finite element analysis (FEA) software COMSOL Multiphysics 5.3a by modifying the linear piezoelectric constitutive equations to include the nonlinear ones in the formulation of coupled equations [2].

B. Nonlinear Harmonics (H2 and H3) of YZ-cut $LiNbO_3$ Rayleigh SAW Resonators.

Figure 1 and 2 show the harmonic generation of 128° YX $LiNbO_3$ SAW resonators and YZ-cut $LiNbO_3$ resonators both operating at the Rayleigh SAW mode for different substrate thicknesses. The second (H2) and third (H3) harmonic responses of Rayleigh SAW are slowly varying curves with some quasi-periodic peak responses [1]. The peak amplitude is due to bulk acoustic waves nonlinearly generated in the substrate and has been verified in both experiments [1] and simulations [2]. We can observe from Figure 2 that as the substrate thickness increase from 150 um to 500 um, the frequency period of quasiperiodic response decrease. The frequency period for 150 um substrate is 7 MHz and the frequency period for 500 um substrate is 2.1 MHz. The product of frequency period and substrate thickness is a constant of 1050 m/s which is different from the 1500~1800 m/s for the YX-128º $LiNbO_3$ case [1], [2]. Furthermore, when the input power is 25 dBm, the H2 power level in both Figure.1 and Figure. 2 are between the range of -60 to -20 dBm while the H3 power level for both is in the range of -120 to -60 dBm. This indicates that the H2 and H3 power level will be close if the SAW resonators operate in the same Rayleigh mode. The denser peak response in YZ-cut is due to faster traveling velocity of the nonlinearly excited bulk waves along the substrate thickness direction.

978-1-6654-3935-0/21/$31.00 ©2021 IEEE

Figure.1 The effect of substrate depth on the harmonic generation of 128° YX $LiNbO_3$ Rayleigh SAW.

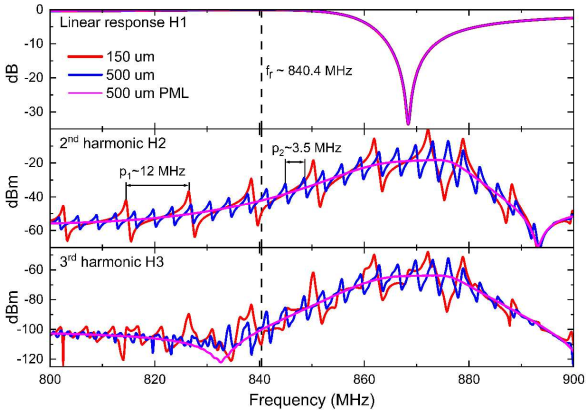
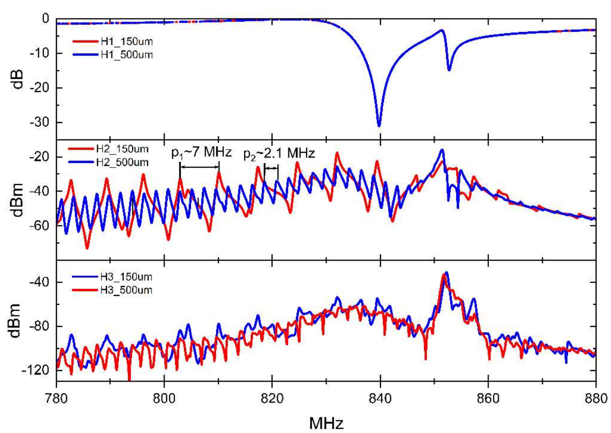


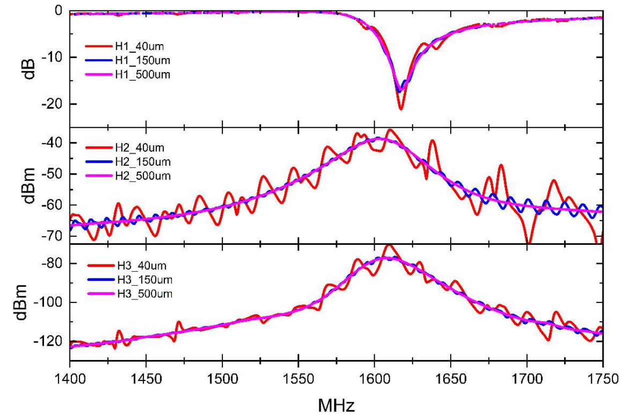
Figure.2 The effect of substrate depth on the harmonic generation of YZ-cut $LiNbO_3$ Rayleigh SAW.



C. *Nonlinear Harmonics (H2 and H3) of YZ-cut $LiNbO_3$ LLSAW Resonators.*

Figure 3 shows the generated harmonic signals of YZ-cut $LiNbO_3$ operating at the frequency of longitudinal leaky mode. We observed that the second (H2) and third (H3) harmonics of LLSAW also exhibited responses with quasi-periodic periods. As the substrate thickness increased from 40 um to 150 um, the frequency period decreased and there were more peaks in a fixed frequency range. The amplitude of these peaks also decreased. When the substrate thickness was increased to 500um, the responses of H2 and H3 harmonics became flat curves without quasiperiodic responses, and the amplitudes of these peaks disappeared. These observations were different from observed in the H2 and H3 harmonics of YX-128º $LiNbO_3$ resonators. Note that the amplitudes of H2 and H3 harmonics in Fig. 2 for Rayleigh SAW were 20 to 30 dBm higher than those in Fig. 3 for LLSAW.

Figure.3 The effect of substrate depth on the harmonic generation of YZ-cut $LiNbO_3$ LLSAW.



III. CONCLUSIONS

The nonlinear harmonic generations of YZ-cut $LiNbO_3$ SAW resonators operating in longitudinal leaky SAW mode and Rayleigh SAW mode were found to be different. For the Rayleigh SAW mode, either in substrate of 128° YX $LiNbO_3$ or YZ-cut $LiNbO_3$, the characteristics of nonlinear harmonics were similar. However, for the YZ-cut $LiNbO_3$ LLSAW mode, we found that the quasi-periodic peaks in the nonlinear harmonic responses would disappear at a thick substrate thickness of 500 µm while those quasi-periodic peaks of the Rayleigh SAW mode were still strong. We also found that the nonlinear harmonic power levels for the LLSAW of YZ-cut $LiNbO_3$ were 20-30 dBm lower than those Rayleigh SAW.

REFERENCES

[1] Solal, M., Kokkonen, K., Inoue, S., Briot, J. B., Abbott, B. P., & Gamble, K. J. (2017). Observation of nonlinear harmonic generation of bulk modes in SAW devices. *IEEE transactions on ultrasonics, ferroelectrics, and frequency control*, *64*(9), 1361-1367.

[2] Pang, X., & Yong, Y. K. (2019). Simulation of Nonlinear Resonance, Amplitude–Frequency, and Harmonic Generation Effects in SAW and BAW Devices. *IEEE transactions on ultrasonics, ferroelectrics, and frequency control*, *67*(2), 422-430.

[3] Yong, Y. K., & Pang, X. (2017, September). Nonlinear frequency response of second harmonic generation in SAW IDT resonators. In *2017 IEEE International Ultrasonics Symposium (IUS)* (pp. 1-4). IEEE.

[4] Holmgren, O., Knuuttila, J. V., Makkonen, T., Kokkonen, K., Plessky, V. P., Steichen, W., ... & Salomaa, M. M. (2005). Imaging surface-acoustic fields in a longitudinal leaky wave resonator. *Applied Physics Letters*, *86*(2), 024101.