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Suppression of Higher-Order Modes of SAW Devices on Layered $LiTaO_3/SiO_2/SiN/Si$ Substrate

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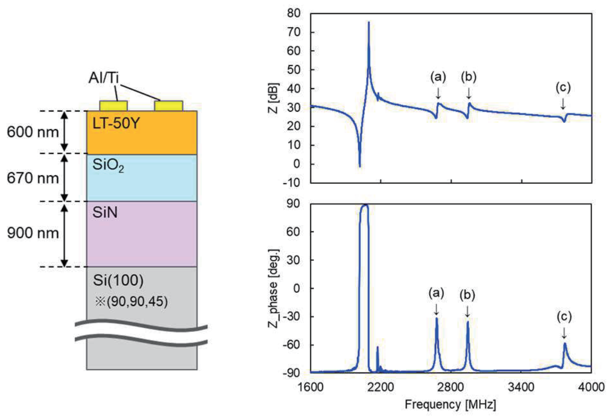
1. Introduction

Incredible high-performance (I.H.P.) SAW devices using very thin $LiTaO_3$ (LT) layer were reported in 2016.[1)] This I.H.P. SAW device realized high Q, low TCF, and good heat dissipation far beyond the conventional SAW devices with mono-layer single-crystal piezoelectric substrate. However, while these excellent performances, some distinctive spurious modes called higher-order modes exist in this type of SAW devices with layered substrate and they sometime lead problems. In particular, they sometimes deteriorate the passband characteristics in multiplexer configuration.

2. Behavior of Higher-Order Modes with Structural Variation

A fundamental structure and a measured impedance characteristic of conventional I.H.P. SAW devices shown in **Fig. 1(a) and (b)**. In Fig. 1(b), three small responses (a), (b), and (c) appear above the main response exist at approximately 2 GHz. In this paper, these are called higher-order mode spurious responses. Since the response of each mode in the impedance phase almost corresponds to the intensity of their responses, it is used as the index value to evaluate the higher-order mode response, here.



(a) Fundamental structure (b) Measured Inpedance characteristic

Fig. 1 Fundamental structure and Impedance characteristic of conventional I.H.P. SAW devices.

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Figs. 2(a), (b) and (c) show the variation of impedance phase of each higher-order mode with thickness of each layer in the layered substrate. In these results, intensity of each higher-order mode tends to be small with decrease of the thickness of each layer with some exceptions such as the dependencies of mode (a) and (c) on the SiO_2 thickness.

Fig. 2(d) shows the LT cut angle dependency of the higher-order modes. It is seen that the intensities of the higher-order modes are influenced by the cut angle of LT and, when the cut angle is zero-degree, the intensities of all three modes become comparably smaller at the same time.

Fig. 2(e) shows dependency of the higher-order modes on the third Euler angle ψ of Si. In this data, mode (a) and (b) have dependency on ψ but mode (c) in not influenced by it. This behavior is probably explained by the anisotropic property of bulk waves in Si substrate. The mode (a) and (b) have leaky u_y (SH) component while mode (c) has leaky u_z (SV) component. These leakages occur due to the coupling between a guided mode and a bulk wave. Since the SH bulk wave in Si(100) has anisotropic property on its surface, the mode (a) and (b) are strongly influenced by the variation of the SH bulk wave velocity. On the other hand, the SV bulk wave in Si(100) has isotropic property on its surface. Therefore, the mode (c) is likely not affected by the angle ψ. This means that the intensities of mode (a), (b), and (c) can probably be controlled if other type of Si substrate such as Si(110) or Si(111) is used as the support substrate.

As it is discussed above, higher-order modes in the I.H.P. SAW structure are influenced by various structural parameters and their behaviors are complicated. Therefore, in this study, FEM simulation is performed by sweeping all those structural parameters which affect the higher-order modes multidimensionally, and the optimized structure is determined from calculation data of huge number.

3. Spurious Free I.H.P. SAW

The optimized structure for higher-order modes suppression is shown in **Fig. 3**. As a result of optimization, Si(111) is chosen as the support substrate and each LT, SiO_2, and SiN layers are considerably thinned. In addition, the cut angle of LT

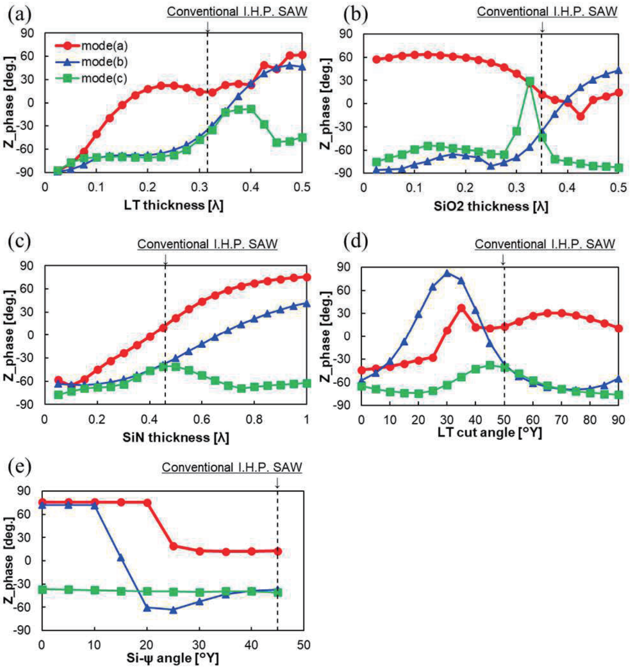

Fig. 2 Variation of impedance phase with (a) LT thickness, (b) SiO_2 thickness, (c) SiN thickness, (d) LT cut angle, and (e) Si-ψ angle.

is adjusted from 50°Y to 55°Y to keep the bandwidth of the main response.

To confirm the validity of the optimization result, a one-port SAW resonator is fabricated and its characteristics are evaluated.

Measured frequency responses of fabricated one-port I.H.P. SAW resonator are shown in **Fig. 4**. In this result, it is clear that the higher-order mode responses up to 4 GHz are markedly suppressed.

Furthermore, Bode-Q of the proposed structure is almost comparable with that of the conventional I.H.P. SAW resonator. By using this structure, I.H.P. SAW which possesses very high performances can be applied to the multiplexer configuration.

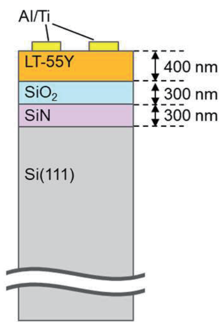

Fig. 4 Structure of spurious free I.H.P. SAW.

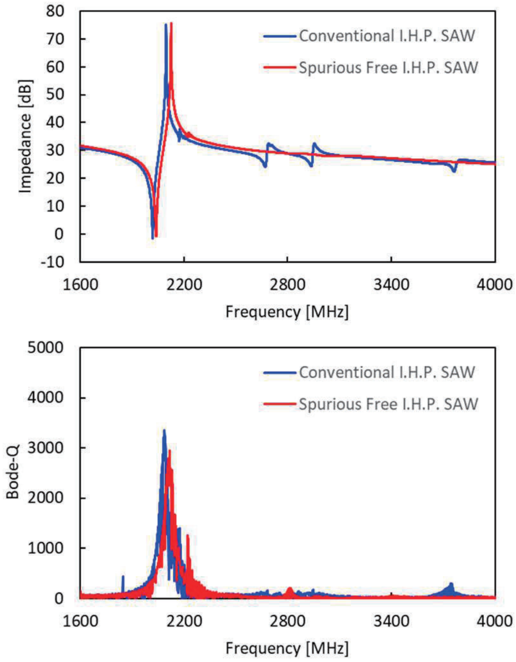

Fig. 3 Measured frequency responses of fabricated one-port resonators.

4. Conclusions

In this paper, behaviors of the higher-order mode responses in I.H.P. SAW resonators were analyzed using FEM simulation and suppression technique of them was discussed. From the FEM analysis, it was confirmed that the thickness of each substrate layer and the cut angle of LT and Si affect to the higher-order mode responses, and therefore, by optimizing these parameters, those responses can be weakened. In addition, on the basis of this result, a one-port I.H.P. SAW resonators with optimized structure was fabricated and its frequency characteristics was evaluated. As a result, it was confirmed that the higher-order mode responses were successfully suppressed, while other characteristics such as bandwidth and Bode-Q are almost comparable with a conventional I.H.P. SAW resonator.

By using this technique, I.H.P. SAW resonators can be applied to the multiplexer configuration.

References

1) T. Takai, H. Iwamoto, Y. Takamine, T. Wada, M. Hiramoto, M. Koshino, and N. Nakajima: IEEE MTT-S Intl. Microwave Symp. Digest (2016) ISBN 978-1-5090-0698-4.