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Analysis of resonance properties for SH_0 mode plate waves on thin $LiTaO_3$/HR-SiC plate

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1. Introduction

Current 5G communication systems and other systems require high-performance RF filter devices. Acoustic wave devices are broadly divided into surface acoustic wave (SAW) devices that use piezoelectric crystals, such as $LiTaO_3$ (LT) and $LiNaO_3$ (LN), and bulk acoustic wave (BAW) devices that use thin films of piezoelectric materials, such as aluminum nitride (AlN) formed on a supporting substrate. SAW devices use SAWs or leaky SAWs that concentrate energy on the surface layer of the piezoelectric body. In thin-film SAW (TF-SAW), a thin piezoelectric body uses bonding substrate and thinning technologies to concentrate the energy even more on the surface of the piezoelectric layer. Recently, these TF-SAW have shown high performance and attracted attention[1,2].

In addition, these bonding and thinning technologies have improved the feasibility of thinning and self-standing plate-wave structures of piezoelectric bodies. Thus, their high performance is expected[3-6]. However, thinned self-standing piezoelectric bodies are very fragile, making their practical application difficult.

In this study, we developed a structure in which thin silicon carbide (SiC) was bonded to a thin plate wave structure piezoelectric body and investigated the effects of changing the structural parameters using the finite element method (FEM).

2. Calculation

2.1 FEM models

We calculated the plate wave resonance characteristics of a thin LT in the conventional and proposed structures shown in **Fig. 1**. In the new structure, epitaxially grown 3C-SiC on a Si substrate was directly bonded to support a self-standing piezoelectric body. Generally, insulators, such as oxide films and high-resistance materials, are preferred as materials for direct bonding to piezoelectric bodies. We used high-resistance SiC (HR-SiC) in this study.

The conventional structure (Fig. 1(a)) and new structure (Fig. 1(b)) have the same interdigital transducer (IDT) electrode structure. In this study, the electrode finger pitch was half the wavelength λ (= 6.4 μm here), and the material was aluminum (Al). The electrode thickness was 0.4λ, and the metallization ratio MR was 0.5. Two electrode fingers formed a pair, and 1V was set to each of them. Both ends of a wavelength, including this pair of IDTs, were the periodic conditions. Each material Q (Q_m) was set to 1000, and the dielectric loss was not considered.

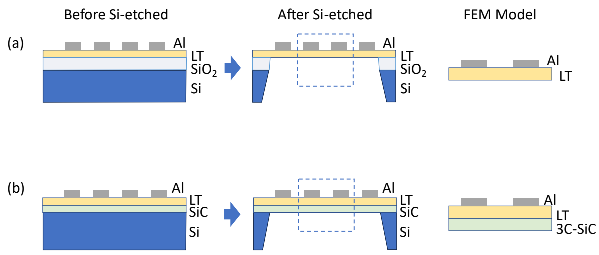

Fig. 1 Self-standing process of piezoelectric body and FEM models for (a) the conventional and (b) proposed structures.

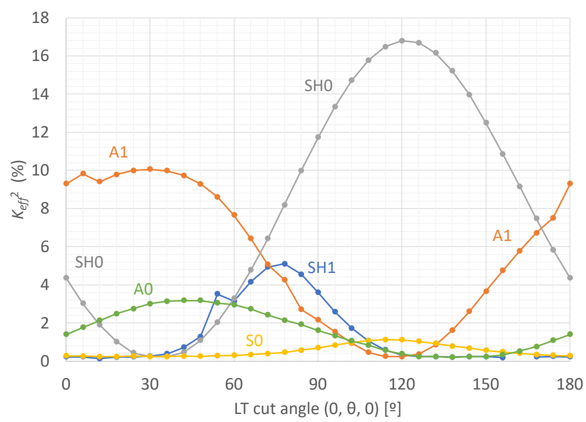

Fig. 2 The LT cut angle (0º, θ, 0º) and simulated K_{eff}^2 of the excitation modes in the conventional structure.

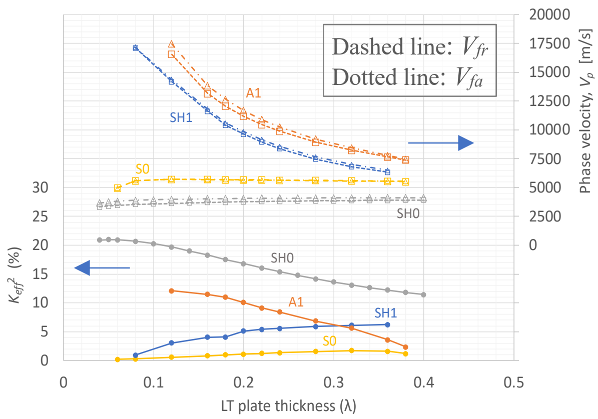

Fig. 3 The LT thickness in λ and simulated K_{eff}^2 and V_p of each mode in the conventional structure.

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2.2 Plate waves on thin LT single plate

As shown in **Fig. 2**, we calculated the LT cut angle and effective electromechanical coupling coefficient K_{eff}^2 of the excitation modes of the plate waves in the conventional structure. The thickness of the LT was 0.2λ, the same as in the reference[6].

Figure 3 shows the resonance characteristics, K_{eff}^2 and phase velocity (V_p), of each mode for different thickness of LT in this conventional structure. In the SH_0 mode, K_{eff}^2 exceeds 20% when the LT thickness was < 0.1λ.

2.3 Plate waves on thin LT/SiC plate

As shown in **Fig. 4**, we calculated the LT cut angle and K_{eff}^2 of the excitation modes of the plate waves in the new structure, where the LT was bonded onto thin 3C-SiC, which was epitaxially grown on a Si substrate. The thicknesses of both the LT and SiC were 0.20λ. In addition, bonding with SiC changed the LT cut angle corresponding to a K_{eff}^2 peak from that of the plate wave of a conventional LT single.

Figure 5 shows the K_{eff}^2 and V_p of each mode corresponding to different thicknesses of LT in the new structure and constant thickness of SiC. In the SH_0 mode, when the LT thickness was 0.28λ, the K_{eff}^2 reached a maximum value of 11.8%. However, when the LT thickness was ≤ 0.2λ, the K_{eff}^2 reduced gradually.

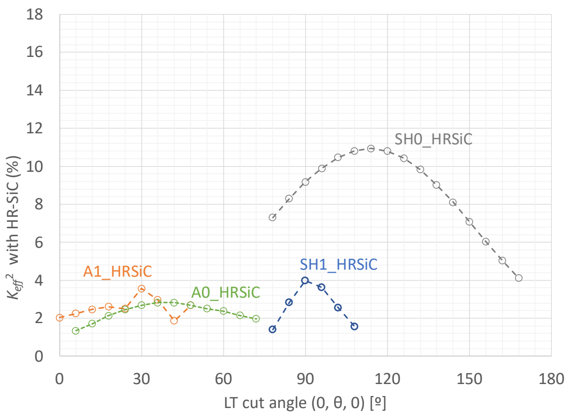

Fig. 4 The LT cut angle (0º, θ, 0º) and simulated K_{eff}^2 of the excitation modes in the new structure.

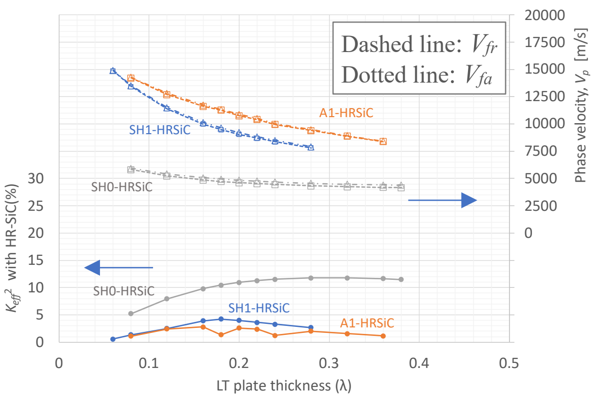

Fig. 5 The LT thickness in λ and simulated K_{eff}^2 and V_p of each mode in the new structure.

The behavior of the phase velocity is influenced by that of SiC owing to the bonding with SiC. Plate wave modes, such as SH_0, which have a slower phase velocity than SiC, have a higher velocity; conversely, SH_1 and A_1, which have a high phase velocity, have a lower velocity.

3. Conclusion

Plate-wave structures, such as RF devices, require a thin and self-standing piezoelectric body, which is difficult to achieve. Bonding a thin SiC film proposed in this study to support a thin piezoelectric body could be a solution. However, the coupling coefficient of the plate wave decreased in all the modes when bonded with HR-SiC.

However, according to calculation results, in the SH_0 mode with originally a large coupling coefficient, the coupling coefficient was found 1.2% larger than that of the LSAW in a bonded substrate state[7]. Thus, it can be considered a sufficiently promising resonance characteristic even by using proposed self-standing plate-wave structure with bonded on thin SiC film.

References

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