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Design of Transversal Piezoelectric Boundary Acoustic Wave Filter for Inverter Drive Circuit

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1. Introduction

Multilevel inverters, which employ a large number of switching (SW) elements to achieve high-efficiency energy conversion, have been extensively studied in power electronics technology. However, the increase in electrical wiring required for each SW element in the inverter control circuit poses challenges in terms of reliability and cost. To address this issue, we propose a gate drive system using surface acoustic wave (SAW) filters that simplifies transmission wiring through frequency multiplexing.[1)] In general, inverter control circuits require strong electrical isolation performance from the power supply source and output. When using the SAW filter, an air gap region located on top of the filter to reduce acoustic loss limits the isolation performance. To enhance isolation performance, we are investigating a piezoelectric boundary acoustic wave (PBAW) device, where the air gap region can be replaced with dielectric materials.

In our gate-drive systems, the PBAW filter must be the transversal-type filter to increase the electrically isolated distance,[2)] which corresponds to the propagation path. However, most research has focused on the resonator-type PBAW,[3)] and consequently, the transversal-type filter has not been widely reported. We propose and demonstrate through calculations that the periodic arrangement of Ta_2O_5 in the propagation path enables the transmission of the boundary wave.[4)] Although the periodic arrangement of Ta_2O_5 provides a good pass characteristic, the Ta_2O_5 thin film fabrication process has not been established yet. As a first step, we tried to realize a transversal-type boundary wave device without using Ta_2O_5. In this study, we report on the design and fabrication of a transversal-type PBAW filter that can be fabricated using only Au electrodes.

2. Design and fabrication of transversal-type piezoelectric boundary acoustic wave filter

Drawing insights from previous studies on the resonator-type PBAW filter, it becomes necessary to increase the electrode thickness compared to the SAW filter to meet the excitation condition of PBAW. However, when the same design

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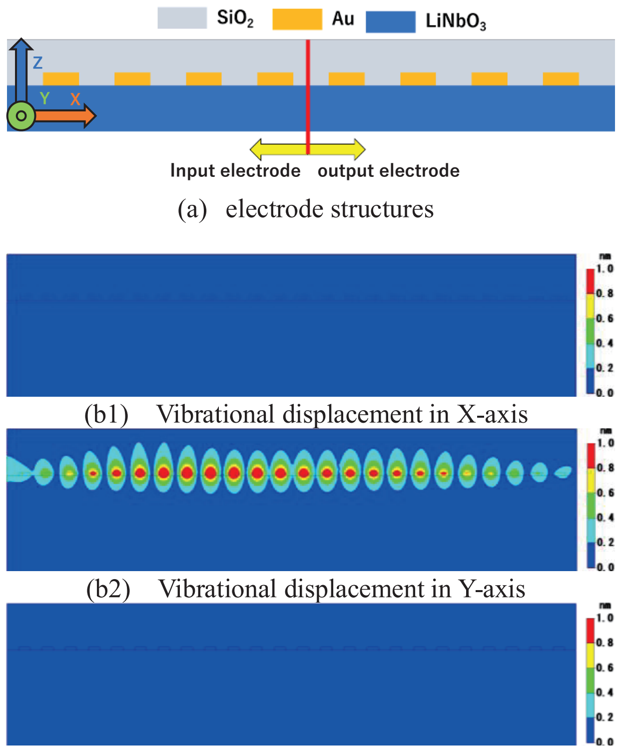
Table I Parameters used for simulation.

Wavelength λ [mm]	9.60, 12.0, 14.4, 19.2
Number of electrode finger pairs *N*	5, 6, 7, 8
Crossing width *W* [mm]	12λ, 17λ, 28λ, 50λ
Electrode thicknesses [mm]	0.06λ
$LiNbO_3$ plate thickness [mm]	3λ
SiO_2 film thickness [mm]	λ, 2λ
Propagation path length [mm]	0.25λ, λ, 8λ,



(a) electrode structures

(b1) Vibrational displacement in X-axis

(b2) Vibrational displacement in Y-axis

(b3) Vibrational displacement in Z-axis

Fig. 1 (a) Electrode structure, (b1, b2, and b3) vibration displacement along x, y, and z axes, respectively.

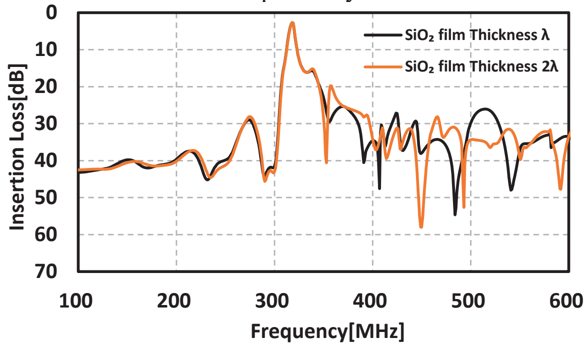


Fig. 2 Frequency response when *N* is 6 and *W* is 28λ.

guideline is applied to the transversal-type filter, significant reflection occurs at the electrode edge, hindering the propagation of PBAW to the receiving electrode. In this study, we addressed this issue by reducing the number of electrode pairs, enabling PBAW propagation to the receiving electrode and suppressing reflection. We utilized a finite element method (FEM) to optimize the interdigital transducer (IDT) design for low insertion loss.

Table I presents the parameters utilized in simulating the transversal-type PBAW filter, where the number of electrode finger pairs was reduced. Additionally, **Fig. 1** displays the calculated vibration displacement. It is evident from Fig. 1 that the vibration displacement is primarily in the Y-axis direction, indicating an SH-type elastic boundary wave. **Fig. 2** demonstrates the transmission characteristics with $\lambda = 9.6$ μm, $N = 6$, and $W = 28$ λ. The minimum insertion loss is 2.67 dB, showcasing favorable propagation characteristics. Furthermore, the frequency characteristics around the passband remain unchanged even with an increase in the SiO_2 film thickness, confirming the device as a boundary wave. Given the good characteristics of the device as a boundary wave device, we considered additional structures for the propagation path based on these design values.

3. Structures of propagation path

We conducted investigations into propagation path structures that can be applied to the transversal-type PBAW filter to verify changes in propagation characteristics. Simulations were carried out for three different structures: (1) a uniform floating electrode, (2) periodic floating electrodes, and (3) periodic floating electrodes with equipotentiality. **Fig. 3** depicts schematic diagrams of these three types of structures.

In the case of the uniform Au floating electrode (1), narrowing of the frequency bandwidth occurs when the propagation path extends beyond 2λ, leading to the generation of many spurious modes. Conversely, with the equipotential floating electrode (3), good transmission characteristics can be achieved without narrowing or generating spurious modes, even if the propagation path extends beyond 2λ. However, it is necessary for each floating electrode to be electrically independent since the electrical insulation performance cannot be improved.

Regarding the periodic floating electrodes (2), which can enhance insulation performance, it is possible to achieve a good insertion loss of 4.30 dB without narrowing or generating spurious modes when the propagation path length is 2λ. Therefore, it is conceivable to realize a transversal PBAW filter using periodic floating electrodes. Since there is no upper limit to the SiO_2 film thickness in this structure, a significant improvement in isolation performance compared to the SAW filter can be expected.

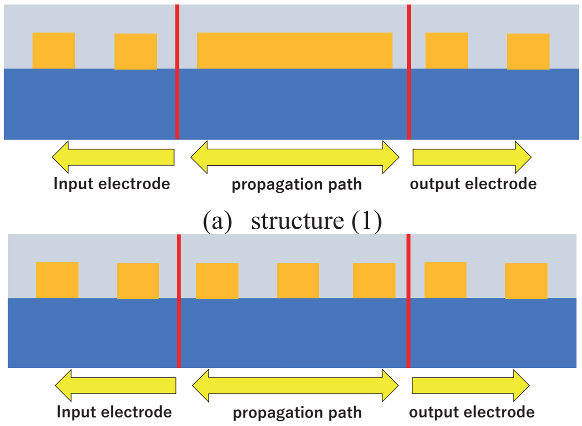


Fig. 3 Propagation path structure.

4. Conclusion

We propose a transversal-type PBAW filter with a $SiO_2/Au/LiNbO_3$ structure for application in inverter gate-drive circuits. We simulated a propagation path structure of periodic floating electrodes capable of propagating elastic boundary waves. The calculation results indicate the possibility of significantly improving the insulation performance using the PBAW filter, which can operate independently of the SiO_2 film thickness. In the future, we plan to investigate the use of Ta_2O_5 and other materials.

Acknowledgments
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