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# High-performance SAW Devices Using Composite Substrate Structures

## 複合基板構造による弾性表面波素子の高性能化

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## 1. Introduction

Since the invention of the interdigital transducer (IDT) in 1965,[1] which efficiently excites a surface acoustic wave (SAW), the excitation, propagation, and resonance properties of piezoelectric crystals, such as quartz, $LiNbO_3$ (LN), and $LiTaO_3$ (LT), and piezoelectric thin films, such as ZnO and AlN, have been widely investigated for application to frequency control, signal processing, and sensor devices. Nowadays, numerous communication systems significantly depend on filters and duplexers utilizing SAWs and bulk acoustic waves (BAWs) because of their small size, high reliability, and high performance. For the development of the fifth-generation mobile communication system (5G) and the realization of next-generation communication systems, SAW and BAW devices with performance higher than the existing ones and having simultaneously a higher frequency, a larger electromechanical coupling factor ($K^2$), a higher quality ($Q$) factor, and a smaller temperature coefficient of frequency (TCF) have been required.

In this talk, first, the type of SAW propagation mode and a method of analyzing the propagation property will be introduced briefly. Then, typical composite substrate structures that have been developed to obtain high-performance SAW devices will be reviewed. In particular, bonded structures comprising an LT or LN thin plate and a quartz substrate will be presented in detail.

## 2. SAW Propagation Modes

Typical SAW propagation modes on a single crystal substrate and a layered structure are Rayleigh-type SAW (R-SAW), shear-horizontal-type leaky SAW (LSAW), and longitudinal-type LSAW (LLSAW). LSAW and LLSAW have a higher phase velocity and a larger $K^2$ than R-SAW; however, they have inherent attenuation because they lose energy by continuously radiating bulk waves into the substrate. For LSAWs on single LN and LT substrates, optimal cuts for eliminating attenuation have been found and implemented in various devices.[2-4] On the other hand, nonleaky LLSAW does not exist on single LN and LT substrates.[5]

A Lamb wave and a shear-horizontal (SH) wave with a large number of modes propagate in piezoelectric plates with finite thickness and are also excited by an IDT.

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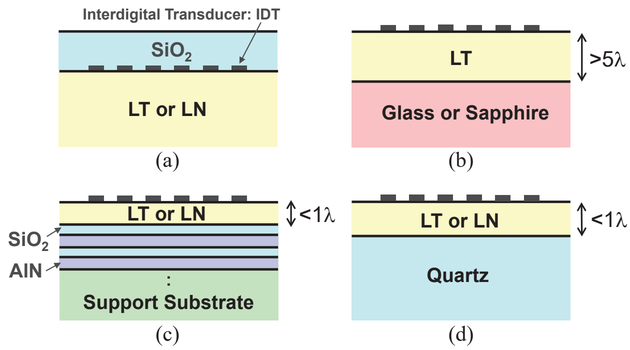


Fig. 1 Typical substrate structures for high-performance SAW devices.[6-34]

## 3. Composite Substrate Structures

**Figure 1** shows typical substrate structures for high-performance SAW devices. Towards realizing a highly stable TCF, $SiO_2$ thin films with an opposite sign of TCF to LT or LN have been utilized as temperature-compensated SAW (TC-SAW) filters, as shown in Fig. 1(a).[6-10] By loading an amorphous thin film, such as $SiO_2$, $Ta_2O_5$, or AlN, to a piezoelectric substrate, the attenuation of LSAW and LLSAW can be controlled because the anisotropy of substrate changes effectively; however, $K^2$ must be reduced in most cases.[11-15] TC-SAW filters have also been realized by bonding an LT plate to a sapphire ($Al_2O_3$) or glass support substrate with a small linear expansion coefficient, as shown in Fig. 1(b).[16-18] In this case, the LT plate thickness is more than 5λ (λ: wavelength).

Recently, an "incredible high-performance (IHP) SAW resonator" with large $Q$ factor and small TCF for LSAW has been reported; this device has a structure formed by combining an LT thin plate with a thickness less than 1λ, and AlN and $SiO_2$ thin films, as shown in Fig. 1(c).[19] Using a LN thin plate and a multilayered acoustic reflector comprising a $SiO_2$/Pt layer, an LLSAW resonator with high frequency and large impedance ratio has been reported.[20] A "hetero acoustic layer (HAL) SAW device" using an LN thin plate and a multilayered thin film with wide fractional bandwidth and large impedance ratio has also been reported for LSAW.[21]

## 4. LT or LN Bonded to Quartz Substrate

The author and research colleagues have found that, in bonded structures comprising a quartz substrate and an LT or LN thin plate with a thickness less than 1λ, as shown in Fig. 1(d), a large $K^2$, a small

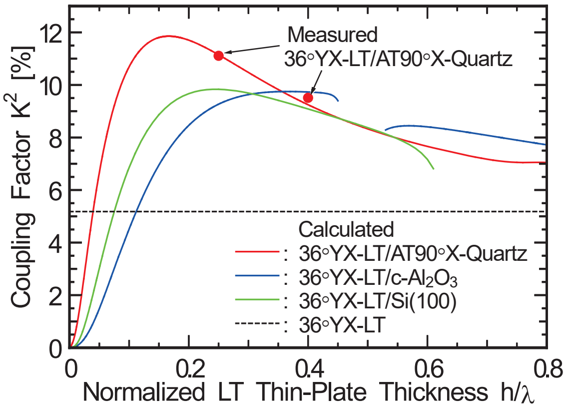


Fig. 2 Calculated and measured $K^2$ of LSAW on 36°YX-LT thin plate bonded to support substrate.[22,23]

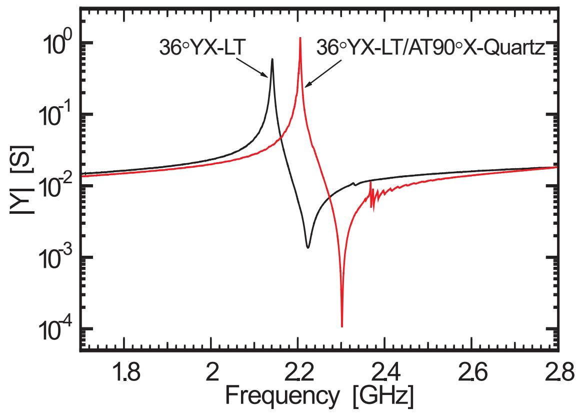


Fig. 3 Measured resonance property of LSAW on 36°YX-LT/AT90°X-quartz with $h$ =0.6 μm and single 36°YX-LT (λ=1.8 μm).[26]

attenuation, and a small TCF can be obtained simultaneously for LSAW and LLSAW.[22-26] Some research groups have also investigated structures bonded to a quartz substrate.[27-33]

**Figure 2** shows the calculated and measured values of $K^2$ for LSAW on 36°YX-LT/AT90°X-quartz as a function of the normalized LT thin-plate thickness $h/\lambda$.[22,23] When utilizing a quartz support substrate, a higher $K^2$ can be obtained because the particle displacements are highly concentrated in the thin plate. Note that the degree of concentration does not necessarily depend on only the phase velocity difference between the thin plate and the support substrate.

**Figure 3** shows examples of the measured resonance property of an IDT-type resonator with an aluminum electrode of λ=1.8 μm, 100.5 finger pairs, and 100 reflectors fabricated on 36°YX-LT/AT90°X-quartz with $h$=0.6 μm or on a single LT substrate.[26] The admittance ratio, fractional bandwidth, and resonance $Q$ factor of LSAW were improved markedly from 53 dB, 3.7%, and 530 for the single LT substrate to 81 dB, 4.2%, and 1,470 for the bonded structure, respectively.

## 5. Conclusions

In this talk, the basic propagation property of SAWs and the composite substrate structures to obtain high-performance SAW devices were presented. By utilizing the structure bonded to a quartz substrate, high-performance properties were achieved for LSAW and LLSAW. The structures can also be applied to acoustooptic[34] and sensor devices. In the future, substrate structures to further increase the performance of SAW devices will be investigated.

## Acknowledgments

The author thanks Prof. Emeritus Y. Nakagawa, Dr. M. Suzuki, graduated and current students of the laboratory of University of Yamanashi, and Prof. J. Mizuno of Waseda University. The author also thanks Mr. K. Kishida and all the people of the Japan Steel Works, Ltd., who helped in fabricating the structure bonded to a quartz substrate.

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