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Longitudinal-Type Leaky SAW on $LiNbO_3$ with High-Velocity Thin Film

高音速薄膜装荷 $LiNbO_3$ 基板上の縦型漏洩弾性表面波

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1. Introduction

Surface acoustic wave (SAW) technologies with higher frequencies are required following the increase in the operating frequencies of communication systems. The longitudinal-type leaky surface acoustic wave (LLSAW) has attracted interest owing to its high phase velocity close to that of a longitudinal bulk wave. However, an LLSAW has huge inherent attenuation owing to the continuous radiation of two types of bulk wave.

Kakio, one of the authors, and Abe proposed a layered structure consisting of air, a bulk $LiNbO_3$ (LN) layer, and an elastically softened LN substrate to reduce the attenuation of an LLSAW.[1] To realize such a layered structure, a reverse proton exchange (RPE) process was applied to X36°Y-LN with a large electromechanical coupling factor K^2 for the LLSAW.[2] The insertion loss and resonance properties of the LLSAW were improved markedly.[1] However, the piezoelectricity was insufficient on almost all of the area of the RPE wafer. A feature of the layered structure is that the velocity on the surface layer is higher than that on the elastically softened substrate. Therefore, by loading with a dielectric thin film with a higher velocity than that of the substrate, the loss reduction of the LLSAW can be expected.

In this study, an aluminum nitride (AlN) thin film was adopted as a high-velocity thin film, and the propagation properties of an LLSAW on an X36°Y-LN substrate, in which an amorphous AlN (a-AlN) thin film was loaded, were investigated theoretically and experimentally.

2. Elastic Constants of Amorphous AlN Thin Film

Using an RF magnetron sputtering system (ANELVA SPF-210A), an a-AlN thin film was deposited on two types of piezoelectric substrate, as described later, without substrate heating. A metal aluminum target with a purity of 4N was used. The RF power applied to the cathode was 150 W. The gas flow ratio of Ar to N_2 was set to 3:8 ccm and the gas pressure was 2.0 Pa. To determine the elastic constants of the a-AlN thin film, which are required for theoretical calculation, a Rayleigh-type SAW (R-SAW) on 128°YX-LN and a shear-horizontal-type SAW (SH-SAW) on 36°YX-$LiTaO_3$ (LT) were chosen as the SAW modes and substrates.[3] Samples with film thicknesses h of 0.1-2.3 μm were fabricated. A simple delay line with a double-electrode interdigital transducer (IDT) pair with a period λ of 20 μm, an overlap length W of 100 λ, eight finger pairs, and a metallized propagation path length L of 100 λ was fabricated on each sample using a 0.01-λ-thick Al film.

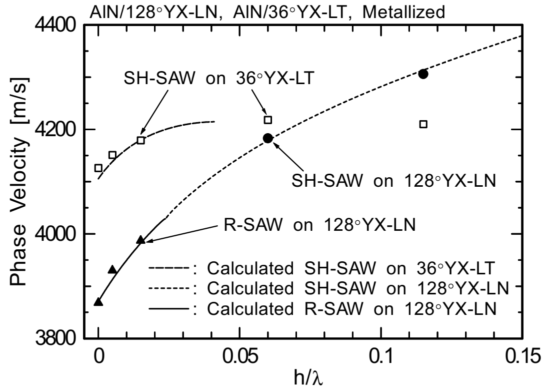

Fig. 1 Phase velocities of R-SAW and SH-SAW.

The phase velocity was determined by multiplying the center frequency of the measured frequency response between the IDTs by λ. The measured phase velocities of the R-SAW on 128°YX-LN and the SH-SAW on 36°YX-LT are plotted in **Fig. 1** as functions of the normalized film thickness h/λ. The phase velocity on 36°YX-LT increased with the film thickness and saturated at a film thickness above 0.05 λ. On the other hand, the phase velocity on 128°YX-LN increased monotonically with the film thickness. For samples with a higher velocity than that of the transverse bulk wave (approximately 4,040 m/s), the SAW mode is considered to be an SH-SAW.[4] Then, the elastic constants c_{11} and c_{44} of the a-AlN thin film were determined so that the difference in the square of the errors between the calculated and measured phase velocities is minimized under the assumption that the values of density ρ and relative permittivity $\varepsilon/\varepsilon_0$ are those of a single-crystal AlN thin film (ρ=3.26×10^3 kg/m^3, $\varepsilon/\varepsilon_0$=9.04).[5]

The calculated phase velocities are also shown in Fig. 1. From the calculation, c_{11} and c_{44} were determined to be 2.69×10^{11} and 1.13×10^{11} N/m^2, respectively, and were 78% and 96% of that of a single

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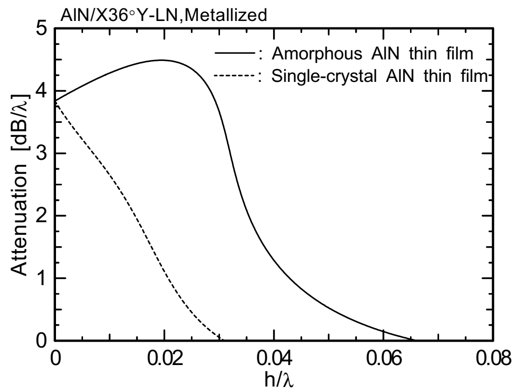

Fig. 2 Attenuation of LLSAW on X36°Y-LN.

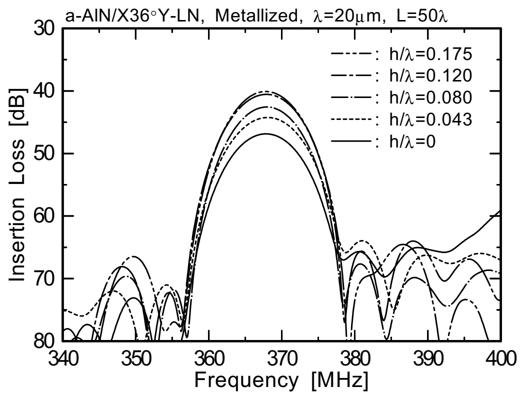

Fig. 3 Frequency responses of LLSAW.

-crystal AlN thin film.[5] The phase velocity of a longitudinal bulk wave on the a-AlN thin film was estimated to be approximately 9,100 m/s from $\sqrt{c_{11}/\rho}$, which is higher than that on the LN substrate.

3. Calculated Attenuation

Figure 2 shows the calculated attenuation of the LLSAW for the metallized electrical condition at the boundary between the a-AlN thin film and X36˚Y-LN substrate using the determined constants. The attenuation increased and then decreased with the film thickness. It was found that an LLSAW without attenuation could be obtained at a film thickness above 0.065 λ. Furthermore, as shown in Fig. 2, it was also found that the attenuation, calculated using the material constants of a single-crystal AlN thin film, for the metallized surface decreased monotonically and vanished at h/λ=0.03.

4. Measured Propagation Properties

Simple delay line samples with an a-AlN thin film were fabricated on X36˚Y-LN substrates. First, a single-electrode IDT pair with λ=20 μm, W=100 λ, and 30 finger pairs was fabricated using a 0.01 λ-thick-Al film. To evaluate the propagation loss *PL*, samples with propagation path lengths of L=5 λ, 25 λ, and 50 λ were fabricated. Next, an a-AlN thin film was deposited on the IDT pair and the metallized propagation path under the sputtering conditions described in §2. The film thickness was varied from 0 (no film) to 0.175 λ so that the thickness with zero attenuation predicted in §3 was included.

Figure 3 shows the frequency responses measured using a network analyzer for L=50 λ. The minimum insertion loss *IL* decreased monotonically with the film thickness. When the film thickness was 0.175 λ, *IL* was 6.8 dB less than that of the sample without a film. **Figure 4** shows the measured *IL* as a function of the propagation path length *L*. There is a nonlinear relation between *L* and *IL*. This is due to the bulk wave radiation loss in the excitation of the LLSAW. *PL* was considered to be the slope of the line

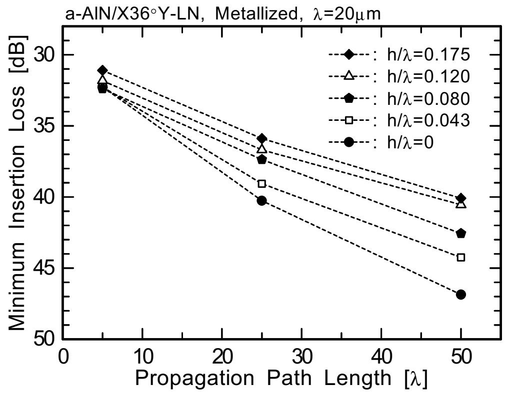

Fig. 4 Minimum insertion loss vs. propagation path length.

between *IL* with a path length of 50 λ and that with a path length of 25 λ. By loading with an a-AlN thin film with 0.12 λ thickness, *PL* was decreased from 0.26 dB/λ for the sample without a film to 0.15 dB/λ. When the film thickness was increased to 0.175 λ, *PL* was slightly increased to 0.17 dB/λ although *IL* decreased. Therefore, it was found that the bulk wave radiation loss was also reduced by loading with an a-AlN thin film.

5. Conclusions

The propagation properties of an LLSAW on a X36˚Y-LN substrate, in which an a-AlN thin film with a higher velocity than that of the substrate was loaded, were investigated. It was found that the losses due to bulk wave radiation can be reduced by loading with an a-AlN thin film. In the future, the propagation properties in the GHz range will be investigated.

References

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