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Loss Reduction of Leaky Surface Acoustic Wave by Loading with High-Velocity Thin Film
高音速薄膜装荷によるリーキー弾性表面波の低損失化

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1. Introduction

Leaky surface acoustic waves (LSAWs) offer a number of beneficial characteristics such as a larger electromechanical coupling factor (K^2) and higher phase velocity than Rayleigh waves. However, LSAWs have inherent attenuation because they lose energy by continuously radiating the bulk wave into the substrate. As a method of decreasing the attenuation, a transformation from an LSAW to a non-leaky Love SAW has been utilized by using heavy-metal gratings or by loading the substrate with a dielectric thin film with a lower velocity than that of the substrate.

On the other hand, the authors proposed a layered structure consisting of a reverse-proton-exchanged layer having a higher velocity than that of the substrate region, and showed that, for an LSAW and a longitudinal-type LSAW (LLSAW) on $LiNbO_3$ (LN) substrates, the attenuation was reduced markedly.[1-3] For an LLSAW, the authors have also shown that its attenuation can be reduced by loading the substrate with an aluminum nitride (AlN) thin film with a higher velocity than that of the substrate.[4,5]

In this study, the propagation properties of LSAWs on rotated *Y*-cut LN substrates loaded with an AlN thin film were investigated theoretically and experimentally.

2. Theoretical Calculation

The phase velocity, attenuation, and coupling factor K^2 of an LSAW on a rotated *Y*-cut *X*-propagating (*YX*) LN substrate with an AlN thin film were calculated by a numerical method. The elastic constants determined for a nonpiezoelectric and polycrystalline AlN thin film deposited using an RF magnetron sputtering system (ULVAC MPS-2000) in the experiment, as described later, were used.[5] The material constants of LN reported by Kushibiki *et al*. were used.[6]

Figures 1 and **2** show the theoretical values of the attenuation under the metallized electrical condition at the boundary between the film and the substrate and the corresponding K^2, respectively, as a function of the rotation angle θ from the *Y* axis. The film thickness *h* normalized by the wavelength λ of the LSAW, *h*/λ, was used as a parameter in these figures. For the case without the film, while the attenuation vanishes at approximately 60°, larger attenuation exists at around the *Y*-cut (θ=0°) having a larger K^2.[7] The rotation angle from the *Y* axis giving zero attenuation shifts from approximately 60° toward 0° as the film thickness is increased. This means that the anisotropy of the substrate can be changed by loading it with a high-velocity thin film.

K^2 decreases monotonically with increasing film thickness owing to the nonpiezoelectricty of the thin film. From these theoretical results, it was found that a combination of the film thickness and rotation angle exists for which zero attenuation and the maximum K^2 can be obtained simultaneously. For *h*/λ=0.065 and θ=17°, a theoretical K^2 of 16.5% was obtained, which was larger than that (12.1%) at the rotation angle giving zero attenuation without a film.

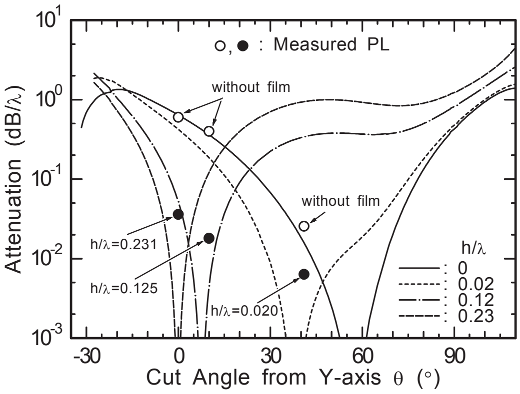

Fig. 1 Calculated attenuation and measured *PL*.

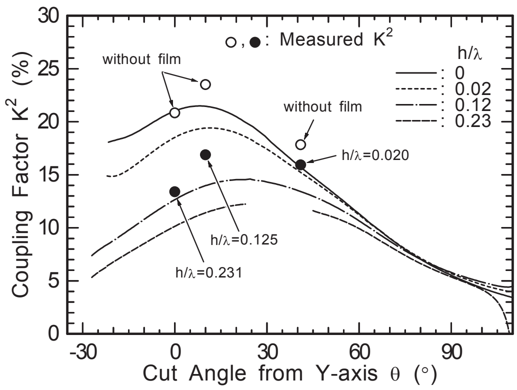

Fig. 2 Calculated and measured coupling factor.

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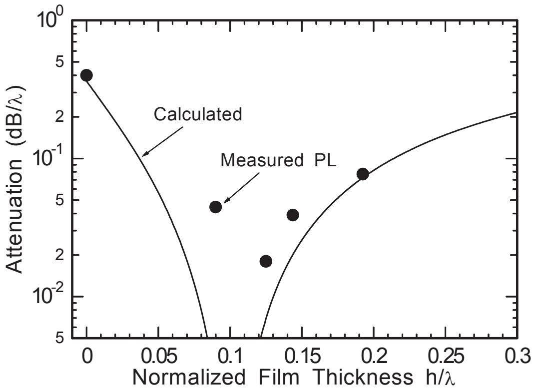

Fig. 3 Calculated attenuation and measured *PL* for 10°*YX*-LN.

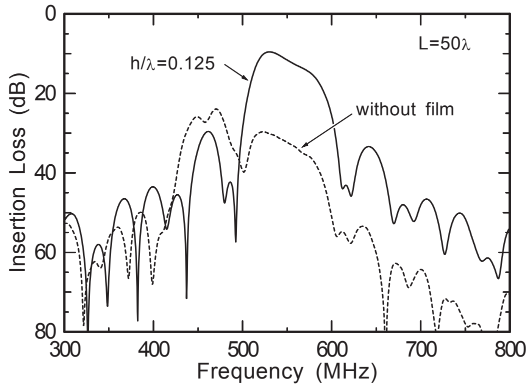

Fig. 4 Frequency responses for 10°*YX*-LN.

As an example for a fixed rotation angle, **Fig. 3** shows the calculated attenuation for θ=10° as a function of *h*/λ. The calculated attenuation was reduced to zero from 0.36 dB/λ for the case without a film by loading the substrate with an AlN thin film of approximately 0.1 λ thickness. Then the attenuation increased with increasing film thickness.

3. Experiment

Substrates with three rotation angles, 0°*YX*, 10°*YX*, and 41°*YX*-LN, were used in the experiment. A single-electrode IDT pair with a period λ of 8 µm was fabricated using a 0.015-λ-thick Al film on the substrates. To evaluate the propagation loss *PL*, samples with propagation path lengths of *L*=10, 25, and 50 λ (*L*=100, 200, and 300 λ for 41°*YX*-LN) were fabricated. Then, an AlN thin film was deposited on the IDT pair and the metallized propagation path by an RF magnetron sputtering system with a long-throw sputter cathode at a substrate temperature of 150°C. Samples with several film thicknesses were fabricated so that the film thickness giving zero attenuation was included.

Figure 4 shows an example of the frequency responses between the input and output IDTs for 10°*YX*-LN and *L*=50 λ. For the sample without a film, the response of the LSAW was observed at a center frequency of 550 MHz, and the minimum insertion loss *IL* was measured to be approximately 30 dB owing to the large propagation loss. When the film thickness was 0.125 λ, *IL* was 20 dB less than that for the sample without the film. The values of *PL* determined from the slope of the *IL* vs propagation length *L* graph are shown in Fig. 3. The film thickness dependence of the measured *PL* was similar to the calculated dependence. After the deposition of the 0.125-λ-thick AlN thin film, the measured *PL* decreased from 0.40 dB/λ for the sample without a film to 0.02 dB/λ.

The values *PL* for each rotation angle with and without the film obtained using a similar evaluation method are shown in Fig. 1. For the results with the film, only the minimum *PL* obtained for each rotation angle is plotted in the figure, and the film thicknesses are also shown in the figure. For each rotation angle, the film thickness giving the minimum *PL* was almost in agreement with the theoretical result. Therefore, it was confirmed experimentally that the rotation angle giving the minimum attenuation shifts toward a smaller rotation angle as the AlN film thickness is increased.

The value of K^2 determined from the measured IDT admittance is also shown in Fig. 2. Except for the case of *YX*-LN without a film, the measured K^2 was larger than the calculated value owing to the internal reflection of the IDT because a single finger was used in the IDT. The film thickness and rotation angle dependences of the measured K^2 were similar to the theoretical results. Therefore, a combination of the film thickness and rotation angle for which zero attenuation and the maximum K^2 can be obtained simultaneously is considered to exist.

4. Conclusions

For rotated *YX*-LN substrates loaded with an AlN thin film, the rotation angle dependences of the propagation properties of LSAWs were investigated. It was found that the minimum attenuation can be obtained at a certain film thickness of the AlN thin film for a rotation angle ranging from 0° to 60° because the rotation angle giving the minimum attenuation shifts toward a smaller rotation angle as the film thickness is increased. By using this structure, a higher velocity than that in the case of a transformation to a non-leaky Love SAW can be obtained.

References

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