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Theoretical analysis of longitudinal wave leaky SAW propagation characteristics on ScAlN film/Quartz or Sapphire substrate

ScAlN 膜を装荷した水晶またはサファイア基板での縦型リーキーSAW 伝搬理論解析

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1. Introduction

Longitudinal leaky surface acoustic waves (LLSAWs) enable a high frequency operation and a wide band width in SAW frequency filters, because of their high phase velocity and high coupling factor K^2. During the LLSAW propagation on a monolayer piezoelectric substrate, SH and SV bulk waves are radiated into the substrate. Therefore, the attenuation of LLSAWs is higher than those of other SAW modes, which causes a low Q factor.

We found that the attenuation in LLSAWs can be decreased by loading high velocity AlN or ScAlN polycrystalline films on piezoelectric substrates [1]. However, the K^2 in these layered structures was significantly decreased. On the other hand, we reported that LLSAW devices with piezoelectric thin plates bonded to high velocity substrates such quartz and sapphire have a high K^2 and a high Q factor [2]. In addition, High K^2 and Q factor LLSAW devises with piezoelectric thin plate/acoustic mirror layer substrate were also reported by Murata manufacturing Co., Ltd[3]. High level boding and polishing techniques were required to obtain a strong bonding interface and a quite thin piezoelectric plate for these structure fabrications.

Recently, several researchers have studied the characteristics of ScAlN film bulk acoustic wave and SAW resonator. The electromechanical coupling coefficient is dramatically enhanced by heavily doping scandium to AlN film.

Figure 1 shows the theoretical K^2 and attenuation of the LLSAW on the (0 ψ=c-axis tilt angle 90) $Sc_{0.4}Al_{0.6}N$ monolayer. The K^2 recaches a maximum of approximately 12% at a c-axis tilt angle of 90º. The attenuation at a c-axis tilt angle of 90º is 10 dB/λ. Although the $Sc_{0.4}Al_{0.6}N$ monolayer is not suitable for LLSAW devices, the layered structure with c-axis parallel ScAlN film/high velocity substrate is expected to have a high K^2 and a high Q factor.

In this study, the propagation characteristics and the admittance properties of LLSAWs on (0 90 90) $Sc_{0.4}Al_{0.6}N$ film/sapphire or quartz substrate were theoretically analyzed. We investigated the effect of the ScAlN film thickness, the cut angle, and the LLSAW propagation direction of the substrate.

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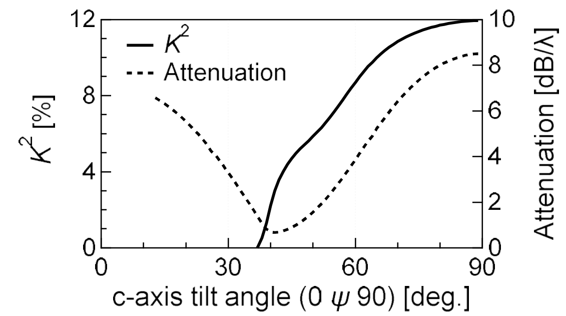

Fig. 1 Theoretical K^2 and attenuation in metalized surface for LLSAW on (0 ψ 90) $Sc_{0.4}Al_{0.6}N$.

2. Theoretical analysis for LLSAW propagation

LLSAW phase velocity, K^2, and attenuation on (0 90 90) $Sc_{0.4}Al_{0.6}N$ film/c-, m-, and R-plane sapphire or AT cut 30-55º X propagation (AT-30-55ºX) and X cut 25-50º Y propagation (X-25-55ºY) quartz substrate were calculated by Farnell and Adler SAW propagation analysis method.

2.1 LLSAW on (0 90 90) $Sc_{0.4}Al_{0.6}N$ film/ Sapphire

The phase velocities of LLSAWs on (0 90 90) $Sc_{0.4}Al_{0.6}N$ film/c-, m-, and R-plane sapphire substrate decreased from the phase velocity of the sapphire with increasing ScAlN film thickness h/λ. As shown in **Fig. 2(a)**, the K^2 increased with increasing h/λ. As shown in **Fig. 2(b)**, the attenuation increased with increasing h/λ from 0 to 0.03. Above h/λ = 0.03, the attenuation is almost constant. The lowest attenuation was observed in the layered structure with ScAlN film/m-plane sapphire.

2.2 LLSAW on (0 90 90) $Sc_{0.4}Al_{0.6}N$ film/ Quartz

The phase velocities of LLSAWs on (0 90 90) $Sc_{0.4}Al_{0.6}N$ film/AT- or X-cut quartz substrate decreased from the phase velocity of the quartz with increasing h/λ. As shown in **Fig. 3(a)** and **Fig. 4(a)**, the K^2 increased with increasing h/λ without depending on the SAW propagation direction of the AT- or X-cut quartz substrate. As shown in **Fig. 3(b)** and **Fig. 4(b)**, the local minimums of the attenuation were observed at h/λ=0.1 in ScAlN film/AT-cut quartz and at h/λ=0.09 in ScAlN/X-cut quartz. The lowest attenuation of 0.003 dB/λ and 0.0003 dB/λ were obtained in ScAlN film/AT-35ºX and X-30ºY Quartz, respectively.

3. FEM analysis

Figure 5(a) shows the admittance properties of LLSAWs on IDT/(0 90 90) $Sc_{0.4}Al_{0.6}N$ film (h/λ =0.16, 0.1, and 0.09)/m-plane sapphire, AT-35ºX quartz, and X-30ºY quartz, simulated by FEM system. The Q factors in these layered structures were higher than that in IDT/$LiNbO_3$. The highest Q factor of 2600 in this study was obtained in IDT/ScAlN film/X-30ºY quartz. The band width of approximately 3.5% in IDT/ScAlN/AT-35ºX or X-30ºY quartz is higher than that of approximately 2.1% in IDT/ScAlN/m-plane sapphire.

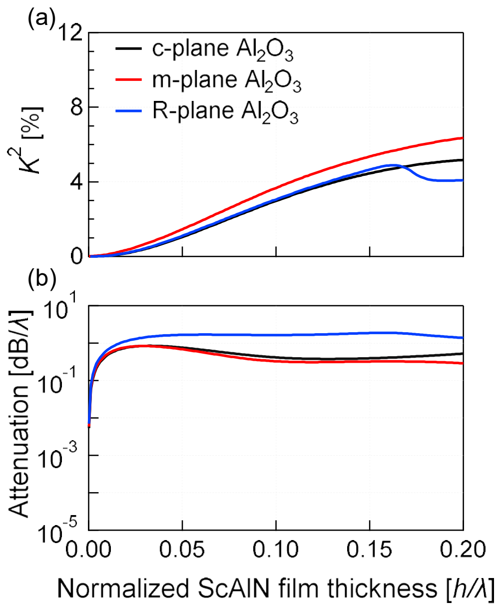

Fig. 2 (a) K^2 and (b) attenuation for LLSAW on (0 90 90) $Sc_{0.4}Al_{0.6}N$ film (h/λ) / c-plane, m-plane, or R-plane sapphire.

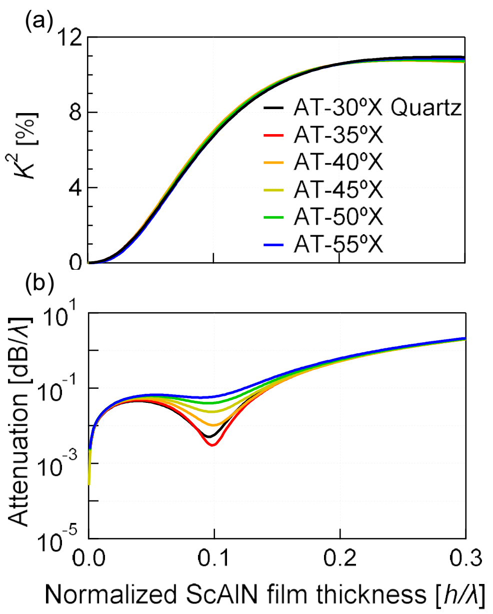

Fig. 3 (a) K^2 and (b) attenuation for LLSAW on (0 90 90) $Sc_{0.4}Al_{0.6}N$ film (h/λ) / AT-30-55ºX quartz.

4. Conclusion

The effects of the ScAlN film thickness, the cut angle, and the SAW propagation direction on LLSAWs characteristics on (0 90 90) $Sc_{0.4}Al_{0.6}N$ film/sapphire or quartz were theoretically investigated. We found that the layered structure with (0 90 90) $Sc_{0.4}Al_{0.6}N$ film/X-30ºY quartz have adequate K^2 and Q factor for SAW filter applications.

References

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3. T. Kimura, et al. : Jpn. J. Appl. Phys. **57** (2018) 07LD15.

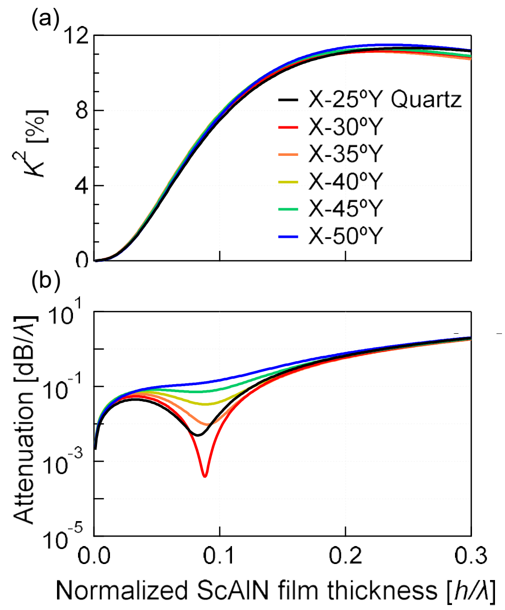

Fig. 4 (a) K^2 and (b) attenuation for LLSAW on (0 90 90) $Sc_{0.4}Al_{0.6}N$ film (h/λ) / X-30-55ºY quartz

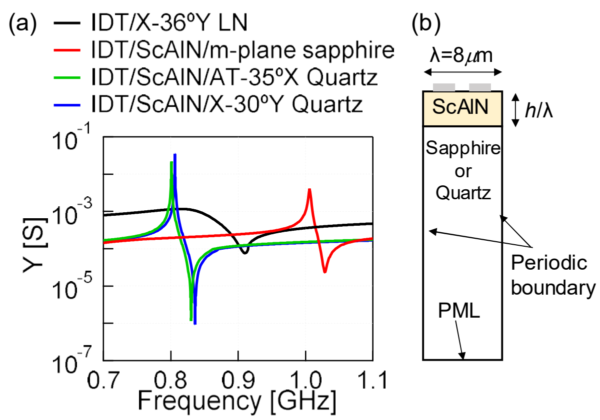

Fig. 5 (a) Frequency characteristics of admittance for LLSAWs on IDT/X-36ºY LN, IDT/(0 90 90) $Sc_{0.4}Al_{0.6}N$ film/m-plane sapphire, AT-35ºX quartz, or X-30ºY quartz, simulated by FEM. (b) The model for the FEM analysis.