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Theoretical Analysis of Leaky SAW Propagation Characteristics on ScAlN film/Quartz

ScAlN 薄膜/水晶上を伝搬するリーキーSAW 伝搬特性の理論解析

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1. Introduction

High performance SAW devices with high phase velocity, high coupling, high Q factor, and high temperature stability are required for applications to frequency filters and duplexers in next generation mobile communications. However, it is difficult for general SAW devices consisting of IDT/piezoelectric single crystal substrate to unite high phase velocity, high coupling, high Q factor, and high temperature stability. In contrast, we experimentally and theoretically demonstrated that leaky SAW (LSAW) and longitudinal leaky SAW (LLSAW) on $LiNbO_3$ or $LiTaO_3$ thin plate bonded to high velocity sapphire or quartz substrate possess high phase velocity, high coupling, low attenuation, and high temperature stability [1,2]. Similarly, I.H.P SAW resonator (piezoelectric thin plate / acoustic mirror layer / substrate) reported by Murata Manuf. [3] and HAL SAW device (piezoelectric thin plate / quartz) reported by Kadota *et al* [4] have these SAW characteristics.

The enhancement of piezoelectricity in Sc doping AlN film was found by Akiyama et al [5]. After that, Hashimoto et al. reported that Rayleigh SAW devices consisting of ScAlN film / high velocity SiC or diamond substrate have high phase velocity and high coupling [6]. In addition, we theoretically demonstrated high coupling and low attenuation of LLSAW on ScAlN film/$LiNbO_3$ substrate and ScAlN film/quartz substrate [7, 8].

In this study, LSAW propagation characteristics on ScAlN film/ rotating Y-cut quartz were investigated theoretically.

2. LSAW characteristics on ScAlN/Quartz

Phase velocity and attenuation of LSAW on air / $Sc_{0.4}Al_{0.6}N$ film / rotating Y-cut (0º θ 0º) quartz were calculated by Farnell and Adler SAW propagation analysis method. The coupling factor K^2 was determined from $K^2 = 2*(v_f-v_m)/v_f$ (v_f: phase velocity in an electrically free surface, v_m: phase velocity in a metallized surface).

Figure 1 shows K^2 of LSAW on (0º θ 50-90º) $Sc_{0.4}Al_{0.6}N$ monolayer. The K^2 recaches a maximum of approximately 6.3% at (0º 90º 60º). The Euler angle of ScAlN films in layered structure analysis models is set to be (0º 90º 60º). On the other hand, the attenuation of LSAW on (0º 90º 60º) $Sc_{0.4}Al_{0.6}N$ monolayer is large (0.13 dB/λ).

LSAW attenuation and K^2 on (0º 90º 60º) ScAlN film (normalized ScAlN film thickness h/λ=0.1, 0.2, 0.4)/((0º θ 0º) quartz are analyzed as a function of θ. As shown in **Fig. 2(a)**, the local minimum attenuation appeared at θ = 129.5º. As shown in **Fig. 2(b)**, K^2 were more than 4.5% at θ = 129.5º. These results show that the optimum Euler angle of quartz is (0º 129.5º 0º) for LSAW on ScAlN / quartz substrate.

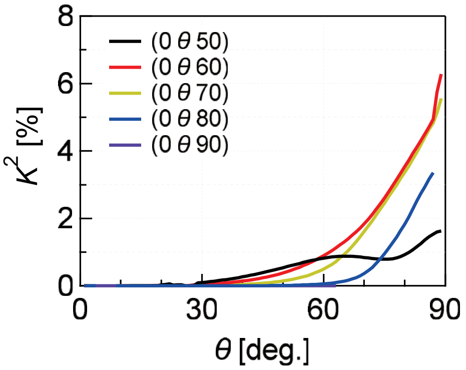

Fig. 1 K^2 of LSAW on (0º θ 50-90º) $Sc_{0.4}Al_{0.6}N$ monolayer.

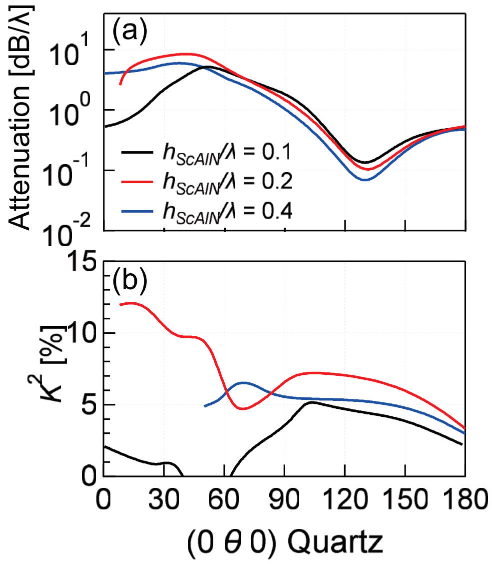

Fig. 2 (a) Attenuation and (b) K^2 of LSAW on (0º 90º 60º) $Sc_{0.4}Al_{0.6}N$ layer on (0 θ 0) Quartz.

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Next, LSAW phase velocity, attenuation, and K^2 on (0º 90º 60-72º) ScAlN film/((0º 129.5º 0º) quartz are calculated as a function of h/λ. As shown in **Fig. 3(a)**, LSAW phase velocities decreased from the phase velocity of the (0º 129.5º 0º) quartz with increasing h/λ. As shown in **Fig. 3(b)**, in (0º 90º 66-72º) ScAlN film/((0º 129.5º 0º) quartz, the local minimum attenuation appeared at h/λ=0.2-0.4. These local minimum attenuations are an order of magnitude lower than that in ScAlN monolayer. As shown in **Fig. 3 (c)**, K^2 reaches a maximum around h/λ=0.2. These K^2 maximum are higher than that of ScAlN monolayers. These results indicated the increase of K^2 and the reduction of attenuation in LSAW on (0º 90º 66-72º) ScAlN/ (0º 129.5º 0º) quartz.

The characteristics of infinite periodic structure LSAW resonators with IDT/(0º 90º 66-72º) $Sc_{0.4}Al_{0.6}N$/ (0º 129.5º 0º) quartz were analyzed by FEM system (Femtet, Murata software). The period λ of a periodic IDT was set to be 8.0 μm. The film thickness of Al for IDTs was 1000 Å. The ScAlN film thickness h/λ were adjusted to be 0.33, 0.28, and 0.23 in (0º 90º 66º), (0º 90º 66º), and (0º 90º 66º) ScAlN film, respectively. **Figure 4** shows the frequency characteristics of admittances of LSAW resonators with IDT/(0º 90º 66-72º) $Sc_{0.4}Al_{0.6}N$/ (0º 129.5º 0º) quartz. We observed LSAW resonances around 560-600 MHz without spurious. **Table I** shows resonance properties of these LSAW resonator. Because of highest Q_r and Q_m factor in IDT / (0º 90º 69º) $Sc_{0.4}Al_{0.6}N$/ (0º 129.5º 0º) quartz, this layered structure is optimum for LSAW propagation

3. Conclusion

LSAW characteristics on $Sc_{0.4}Al_{0.6}N$ film/ rotating Y-cut quartz were invesigated theoretically. We demonstrated that LSAW on (0º 90º 66-72º) $Sc_{0.4}Al_{0.6}N$ film/(0º 129.5º 0º) quartz have higher K^2 and lower attenuation than ScAlN monolayer..

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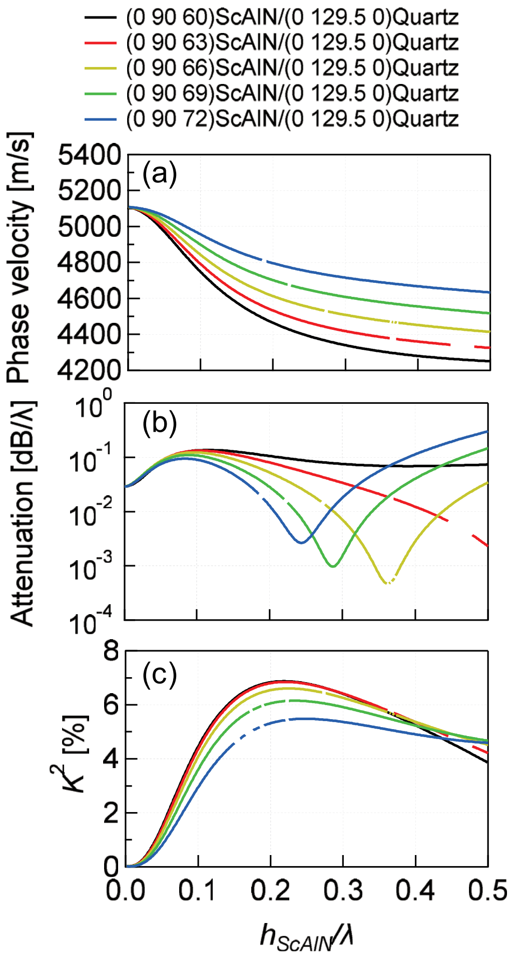

Fig. 3 (a) Phase velocity, (b) attenuation, and (c) K^2 of LSAW on (0º 90º 60-72º) $Sc_{0.4}Al_{0.6}N$ layer on (0º 129.5º 0º) Quartz.

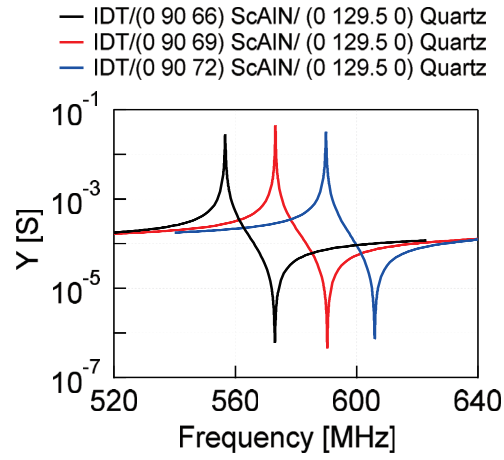

Fig.4 Admittance frequency characteristics of LSAW on ScAlN/Quartz simulated by FEM.

Table I Fraction bandwidth, Q_r and Q_a factor in LSAW resonators with ScAlN/quartz.

Euler angle of $Sc_{0.4}Al_{0.6}N$ film	Fractional bandwidth [%]	Admittance ratio [dB]	Q_r	Q_a
(0º 90º 66º)	2.9	93	3,570	4,060
(0º 90º 69º)	2.9	100	5,210	5,620
(0º 90º 72º)	2.7	93	3,910	4,013