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Development of SAW Resonator with Good Temperature Coefficient of Frequency using $SiO_2/Al/LiNbO_3$ structure

$SiO_2/Al/LiNbO_3$構造を用いた良好な温度特性を有するSAW共振器の開発

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1 Introduction

The surface acoustic wave (SAW) duplexer is a key device of mobile phones for miniaturization and high performances. In the universal mobile telecommunication system (UMTS), Band II, III, and VIII systems have narrow duplex gap. To realize the duplexers with small size, low insertion loss, and high attenuation for these applications, SAW resonators with small temperature coefficient of frequency (TCF) are required in addition to moderate electromechanical coupling coefficient (K^2). Recently, several attempts have been reported on the TCF improvement. For moderate K^2 (~8%), a flattened $SiO_2/Cu/LiTaO_3$ structure, a shape controlled $SiO_2/Al/LiTaO_3$ structure, and a flattened SiO_2/Cu/~128°YX-$LiNbO_3$ substrate structure were investigated.[1-3)] For large K^2 (~15%), on the other hand, a SiO_2/Al/low cut angle YX-$LiNbO_3$ structure was also discussed.[4-6)]

This paper describes use of this structure for realization of SAW resonators with small TCF (~0 ppm/°C) with moderate K^2. Although setting the SiO_2 thickness large makes zero TCF possible with slight K^2 reduction, strong spurious responses due to Rayleigh SAWs appear. It is shown that they can be suppressed well by properly setting the top shape of the SiO_2 layer.

2. Structure of SAW resonator with SiO_2 film

We employed the 1-port resonator as a test device. **Fig. 1** shows a cross-sectional view of the SiO_2/Al /5°YX-$LiNbO_3$ structure. Above the IDT electrodes (Al-alloy), the SiO_2 film is deposited. The convex top shape is controlled by adjusting the deposition condition.[2,5,6)] In the following experiments, the electrode thickness is fixed at 160 nm (0.08λ), where λ is the IDT period of 2.0 μm. The numbers of the IDT and reflector electrodes are 149 and 30, respectively, and the aperture length is 46.5 μm. The apodization was applied to the IDT to suppress the transverse mode responses.

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Input admittance (Y_{11}) was measured for series of fabricated SAW resonators, and f_r and f_{ar} were estimated from two frequencies giving the maximum and minimum $|Y_{11}|$. It should be noted that this estimation may include certain errors when strong spurious responses exist near the main resonance. From thus estimated f_r and f_{ar}, K^2 was calculated by the formula

$$K^2 = (\pi/2)(f_r/f_{ar})\tan[(\pi/2)\{(f_{ar}-f_r)/f_{ar}\}]. \quad (1)$$

3. Characteristics of SAW resonator on SiO_2 film without shape control

First, we studied the dependence of TCF and K^2 of SH SAW on the SiO_2 thickness h.

Fig. 2 shows the frequency dependence of admittance (Y_{11}) of the SAW resonator when h is chosen as a parameter. Relatively strong spurious responses are seen near the main resonance when h>0.25λ. These spurious responses are caused by the Rayleigh SAW.

Fig. 3 shows the TCF at resonant and antiresonant frequencies f_r and f_{ar}, respectively, and K^2 of SH SAW as a function of h. It is seen that TCFs for f_r and f_{ar} increase with an increase in h, and become almost zero when h is set at 0.30λ. Although K^2 of SH SAW gradually decreases with an increase in h, it is still relatively large (~8%) at h=0.30λ, where zero TCF is achievable.

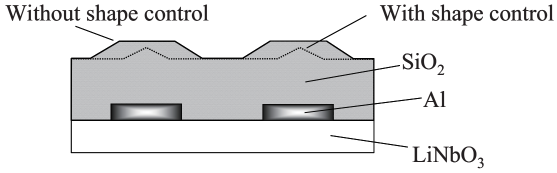

Fig. 1 Cross sectional view of $SiO_2/Al/LiNbO_3$ structure

4. Suppression of Rayleigh-mode spurious response

As discussed above, we have demonstrated that the SiO_2/Al/5°YX-$LiNbO_3$ structure offers zero

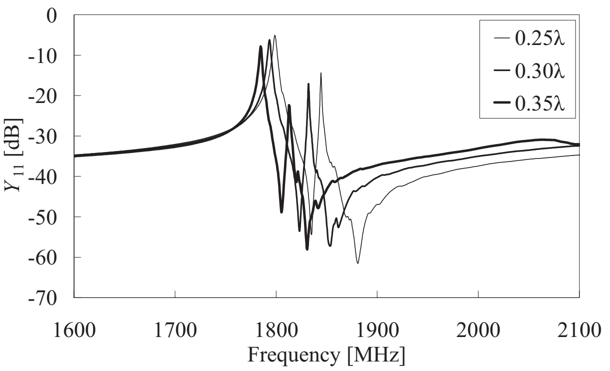

Fig. 2 Dependence of admittance (Y_{11}) of SAW resonator on SiO_2 thickness without cross-sectional shape control

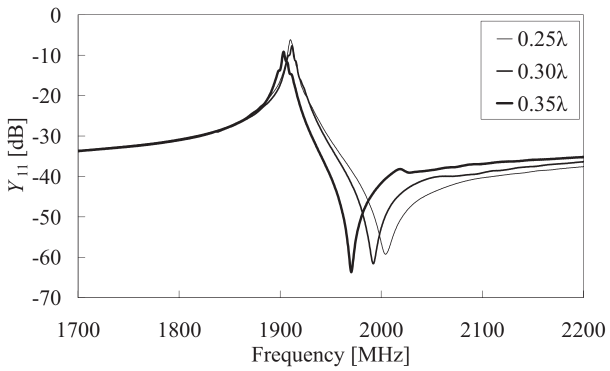

Fig. 4 Dependence of admittance (Y_{11}) of SAW resonator on SiO_2 thickness with cross-sectional shape control

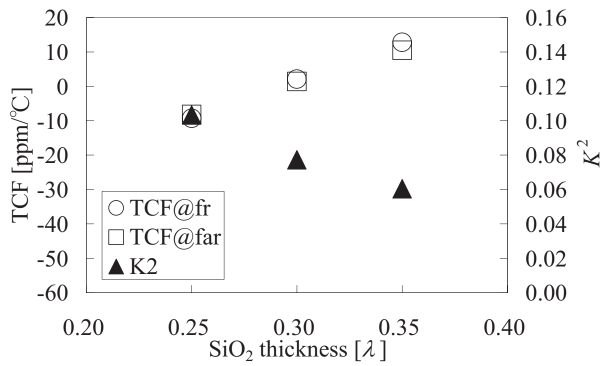

Fig. 3 TCF and K^2 of SH SAW as a function of the SiO_2 thickness without cross-sectional shape control

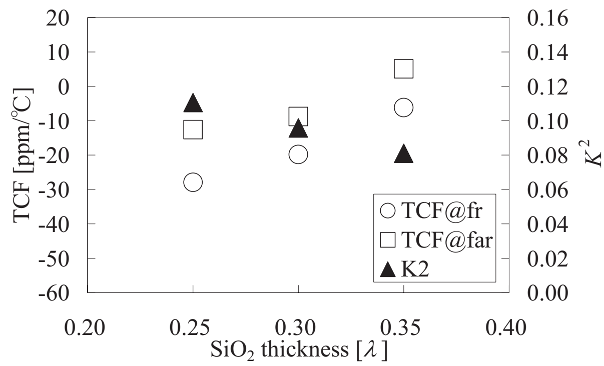

Fig. 5 TCF and K^2 of SH SAW as a function of the SiO_2 thickness with cross-sectional shape control

TCF in addition to moderate K^2 when h is set at 0.30λ. For practical applications, we must suppress the strong spurious response due to the Rayleigh SAW sufficiently.

Here we apply the SiO_2 shape control technique for suppression of the spurious response caused by the Rayleigh SAW.[5, 6] We modified the deposition condition, and investigated how the spurious response changes with the cross-sectional shape of SiO_2 top surface. The result indicated that reduction of the SiO_2 convex shape is effective to suppress the spurious response when SiO_2 thickness is large (see Fig. 1).

Fig. 4 shows the frequency dependence of Y_{11} when the SiO_2 shape above the IDT is adjusted properly for each h. It is seen that the spurious response is suppressed completely for all these cases.

Fig. 5 shows the TCF at f_r and f_{ar} and K^2 of SH SAW as a function of h. TCF becomes almost zero when h is set at 0.35λ, where moderate K^2 of about 8% is simultaneously achieved.

It should be noted that the optimal SiO_2 thickness is different for the result (0.30λ) without the shape control described above. This may be due to the difference in total volume of the SiO_2 layer. The coupling with the Rayleigh mode may also contribute to the difference.

5. Conclusion

It was demonstrated that the SiO_2 shape control technique is effective for the suppression of the Rayleigh-mode spurious response caused in the temperature compensated SAW resonator using the $SiO_2/Al/LiNbO_3$ structure with relatively thick SiO_2. This feature indicates feasibility of the $SiO_2/Al/LiNbO_3$ structure to the development of SAW duplexers with narrow duplex gap.

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