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Study of Relationship between Cut Angle of Substrate and Characteristics of SAW Resonators with Shape-controlled SiO_2

形状制御されたSiO_2膜を有するSAW共振子の特性と基板のカット角の関係に関する研究

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1. Introduction

The Surface Acoustic Wave (SAW) filters, which are widely used in cellular phones of the universal mobile telecommunication system (UMTS) as key devices. Realization of various filter characteristics is demanded to satisfy the specification of every band in UMTS. The performance of a SAW filter is primarily determined by piezoelectric substrate material properties and SAW filter design. To coat IDT with SiO_2 is often used to improve the temperature characteristics of SAW filter[1-2)]. In general, an additional artifice is needed to realize good filter performance because the SiO_2 coating degrades SAW filter performances[3-5)]. The shape-control of SiO_2, which we have developed and investigated, is one of the techniques for resolving this problem[4-5)].

In previous study, we investigated the optimal shape of the SiO_2 layer to bring out good performance of SAW filters in the SiO_2/IDT/$LiTaO_3$ system[4)]. A leaky-SAW propagation characteristic is affected by surface conditions of the substrate, and it is known the optimum cut of $LiTaO_3$ is necessary to be decided with respect to such condition[6)].

In this paper we examine the relationship between a cut angle of substrate and characteristics of SAW resonators with shape-controlled SiO_2 in SiO_2/IDT/$LiTaO_3$ system.

2. Material and Method

The one-port SAW resonators were employed as test devices. **Fig.1** shows a cross-sectional view of SiO_2/IDT/$LiTaO_3$ structure. The SiO_2 layer was deposited above IDTs made of Al-Cu alloy. In this paper, the thickness of SiO_2 layer is fixed to approximately 0.2λ, and the shape parameters EA and ED shown in Fig.1 defining the convex top of SiO_2 is EA≈23° and ED≈0λ respectively. Here, λ is the IDT period (2*p*) of 2.15μm. The number of the IDT electrodes is 300 (150 pair) and the number of reflector electrodes is 100. The aperture length is 20λ. The thickness of IDT electrode is fixed at 0.07λ.

For the evaluation of SAW resonator performance, the electromechanical coupling coefficient (k^2), the reflection coefficient (γ), and the quality-factor (Q-factor) at the resonant frequency (f_r) and that at the antiresonant frequency (f_{ar}) were calculated using following formulas: .

$$k^2 = (\pi/2)\,(f_{ar}/f_r)\tan[(\pi/2)\{(f_{ar}-f_r)/f_r\}]$$

$$\gamma = \pi\,(f_u - f_L)/(2pf_0) \cong \pi\,(f_u - f_L)/V_B$$

where V_B is the BAW velocity of $LiTaO_3$. Here f_r and f_{ar} were estimated from frequencies giving the maximum and minimum in the admittance $|Y_{21}|$, respectively. The upper end of the stop band (f_u) was estimated from the frequency of spurious responses which appears at a frequency higher than f_{ar}. The lower end of the stop band (f_L) is estimated from f_r.

We also simulated the characteristics of test devices by the finite element method (FEM) / spectrum domain analysis (SDA)[7)].

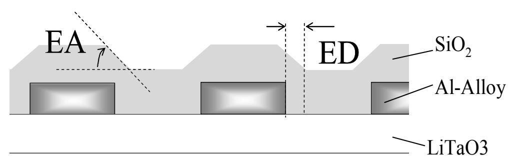


Fig.1 Cross sectional view of SiO_2/IDT/$LiTaO_3$ structure

3. Results and Discussion

Fig.2 shows the frequency dependences of admittance (Y_{21}) of SAW resonators as a function of the rotation angle θ for rotated Y-cut $LiTaO_3$ substrate. It is seen that the magnitude of anti-resonance admittance ($|Y_{far}|$) decreases with θ. On the other hand, the magnitude of resonance admittance ($|Y_{fr}|$) takes a maximum at θ = 39 degree. As the result, highest value of the admittance ratio ($|Y_{fr}/Y_{far}|$) is achieved when the 42° Y-X $LiTaO_3$ substrate is used.

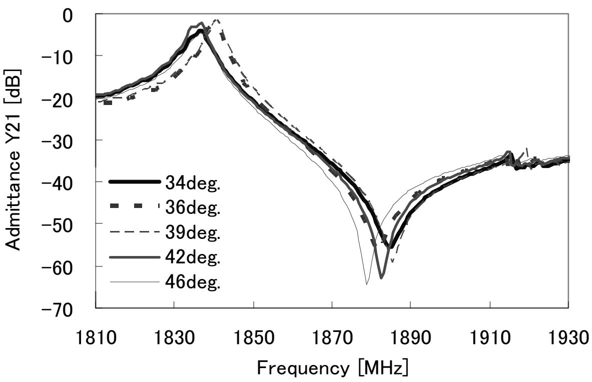
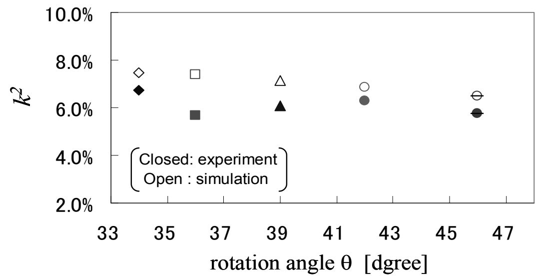


Fig.2 Frequency dependences of Y_{21} of SAW resonators as a function of the rotation angle θ for rotated Y-cut $LiTaO_3$

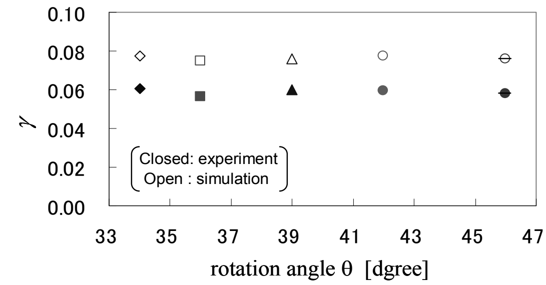
The evaluated k^2 and γ are shown in **Fig.3** (a) and (b), respectively. In these figure, simulated results also shown together. In both k^2 and γ, the tendencies of simulation results and experimental results are in good agreement. We see from this figure, θ has little effect on γ but k^2 decreases slightly as θ increases.

Fig.4 shows the relationship between θ and Q-factor of SAW resonators. In this figure, circles show the Q-factor at f_r (Q_r) and triangles show the Q-factor at f_{ar} (Q_{ar}). In the figure, open circles and triangles indicate the simulation results while black ones indicate the experimental ones. The experiment results agree qualitatively with the simulation. However, experimental Q_r is smaller than the simulation whereas the experimental Q_{ar} is larger than the simulation. This may be due to lateral power leakage, which was reported to be obvious near the resonance frequency for the $LiTaO_3$ substrate[8].

And Q_{ar} is always higher than Q_r in the experiment. From these results, we can conclude that optimal balance between Q_r and Q_{ar} can be achieved when θ = 39-42 degree is chosen for the $LiTaO_3$ substrate.



(a)



(b)

Fig.3 Rotation angle dependence of k^2 and γ of SAW resonator with shape-controlled SiO_2. (a) k^2 vs. θ, (b) γ vs. θ

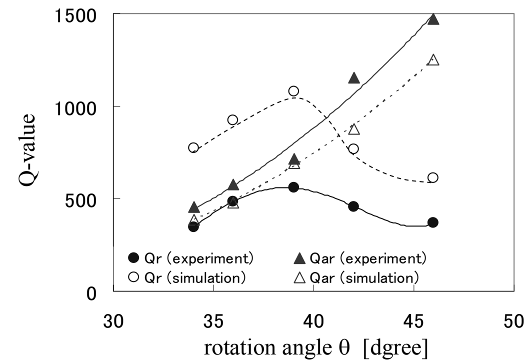


Fig.4 relationship between θ and Q-factor of SAW resonators

4. Conclusion

We investigated the dependency of characteristics of SAW resonators on the rotation angle θ for rotated Y-cut $LiTaO_3$ substrate in shape-controlled SiO_2/IDT/$LiTaO_3$ system when the IDT and SiO_2 thickness are 0.07λ and 0.2λ, respectively. We saw θ has little effect on γ but k^2 decreases slightly as θ increases. There was different dependency between Q_r and Q_{ar} on θ. It was shown that $LiTaO_3$ substrate with the rotation angle θ of 39-42 degree gives the optimal balance between Q_r and Q_{ar} in this system.

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