Development of High Coupling Coefficient SAW Resonator on Ta$_2$O$_5$/Al/LiNbO$_3$ Structure

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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 IV system has the largest duplex gap of 355 MHz. Therefore, to realize the duplexer with small size, low insertion loss, and high attenuation, the SAW resonator having very high coupling coefficient ($K^2$) is required. Recently, a combination of the low cut angle Y-cut LiNbO$_3$ substrate and SiO$_2$ film$^1$ and a combination of a 15°YX-LiNbO$_3$ substrate and a Cu electrode$^2$ for wideband applications are reported. For the duplexers with wide duplex gap, a flattened SiO$_2$ film /Cu electrode/LiNbO$_3$ substrate$^3$ and a shape controlled SiO$_2$ film /Al electrode/LiNbO$_3$ structure$^4,5$ were reported. On the other hands, the approach of using Ta$_2$O$_5$ film has never been reported. In this report, we developed the high $K^2$ SAW resonator on a Ta$_2$O$_5$/Al/LiNbO$_3$ structure.

2. Structure of SAW resonator with Ta$_2$O$_5$ film

We employed the 1-port resonator as a test device. Fig.1 shows a cross-sectional view of the Ta$_2$O$_5$/Al/LiNbO$_3$ structure. Above the IDT electrodes, the Ta$_2$O$_5$ film is deposited by RF sputtering. The piezoelectric substrate is a 5°YX-LiNbO$_3$ substrate. The IDT electrodes consist of Al-alloy. The Al electrode thickness is 160 nm (0.08µ). Regarding the SAW resonator structure, a pitch of the IDT electrodes is 1.0 µm. The number of the IDT electrodes and the reflector electrodes are 150 and 30, respectively. And, aperture length is 25 µm.

Fig. 1 Cross sectional view of Ta$_2$O$_5$/Al/LiNbO$_3$ structure

3. Characteristics of SAW resonator with Ta$_2$O$_5$ film

Fig.2 shows the admittance ($Y_{11}$) of SAW resonator dependence of Ta$_2$O$_5$ thickness. Some spurious responses appearing between the resonant and the antiresonant frequencies are due to transverse-mode in Fig.2. Fig.3 shows the dynamic range of $Y_{11}$ as a function of the Ta$_2$O$_5$ thickness. Fig.4 shows the phase velocity at resonant and antiresonant frequency as a function of the Ta$_2$O$_5$ thickness. The phase velocity is calculated by multiplying resonant or antiresonant frequency by IDT pitch on each resonator. And, dashed-line is the phase velocity of slow shear wave of the LiNbO$_3$ substrate.

As shown Fig.2, the characteristic of SAW resonator without Ta$_2$O$_5$ film degrades. Especially, an attenuation at antiresonant frequency degrades. And, as shown Fig.3, the dynamic range of $Y_{11}$ is very small. On the other hand, the characteristic of SAW resonator with Ta$_2$O$_5$ film does not degrade at antiresonant frequency. Because, as shown Fig.4, when the Ta$_2$O$_5$ thickness becomes more than 0.0125λ, the phase velocity at antiresonant frequency becomes slower than the phase velocity of slow shear wave of the LiNbO$_3$ substrate. So, the bulk radiation does not occur. However, the dynamic range of $Y_{11}$ decreases as the Ta$_2$O$_5$ thickness increases. Therefore, the optimum thickness of Ta$_2$O$_5$ is determined in views of the dynamic range of $Y_{11}$ and the Rayleigh-mode spurious response.

Fig. 2 The admittance ($Y_{11}$) of SAW resonator dependence of Ta$_2$O$_5$ thickness
3. $K^2$ and Rayleigh-mode spurious response of SAW resonator dependence of the Ta$_2$O$_5$ thickness

We investigated the level of Rayleigh-mode spurious response and the $K^2$ dependence of the Ta$_2$O$_5$ thickness. Fig.5 shows the dynamic range of Rayleigh-mode spurious response as a function of the Ta$_2$O$_5$ thickness. Fig.6 shows the $K^2$ as a function of the Ta$_2$O$_5$ thickness. As shown Fig.5, the dynamic range of Rayleigh-mode spurious response becomes zero when the Ta$_2$O$_5$ thickness is 0.025$\Lambda$. In addition, the dynamic range of $Y_{11}$ has sufficient value. And, as shown Fig.6, although the $K^2$ decreases as the Ta$_2$O$_5$ thickness increases, the $K^2$ is very high of 23%. We have cleared the optimum Ta$_2$O$_5$ thickness to realize the high performance SAW resonator without Rayleigh-mode spurious response.

4. Conclusion

We have established the SAW resonator on Ta$_2$O$_5$/Al/5°YX-LnBo$_3$ structure for wide duplex gap application. The SAW resonator shows the excellent performance with high $K^2$. The SAW resonator could be applied sufficiency for Band IV duplexer. Moreover, the density of Ta$_2$O$_5$ is higher than that of SiO$_2$. So the Ta$_2$O$_5$ thickness, which the bulk radiation does not occur, is thinner comparing with the SiO$_2$ thickness.

References