This paper describes the novel spurious suppression technique for SiO$_2$/Al/LiNbO$_3$ structure. Regarding the Rayleigh-mode spurious, it can be suppressed by controlling the cross-sectional shape of a SiO$_2$ overlay deposited on resonator electrodes. Regarding the transverse-mode spurious, it can be suppressed by selectively removing the SiO$_2$ overlay from the dummy electrode region for enhancing the SAW energy confinement in the active electrode region.

We applied the proposed technique to the development of a miniature W-CDMA duplexer on a 5º Y-X LiNbO$_3$ substrate. The developed SAW duplexer was installed into a 2.5 mm×2.0 mm package, and exhibited low insertion loss, high out-of-band rejection and small TCF. The insertion losses in the Tx and Rx bands are 1.2 dB and 1.9 dB, respectively, the isolations are 53 dB in Rx band and 45 dB in Tx band, and the TCF is about -30 ppm/ºC, respectively.

1. Introduction

The SAW duplexer is a key device for the mobile phones. It needs high quality characteristics of low insertion loss, high attenuation and high power durability. Furthermore, the SAW duplexer is required the miniaturization as mobile phone becomes smaller. Substrate materials mainly limit and determine the performance of SAW duplexers; for their application to Band V in the standard of Third Generation Partnership Project (3GPP), conventional 36-48ºY-cut LiTaO$_3$ substrates are very promising for their moderate electromechanical coupling coefficient $K^2$ and temperature coefficient of frequency (TCF). As to Bands II, III, and VIII with narrow duplex gaps between the transmitting (Tx) and receiving (Rx) bands, a smaller TCF should be given priority over a larger $K^2$ in search for the substrate material, and various configurations were proposed to fulfill the requirement. On the other hand, as to Bands I, IV, and X with large passband widths and wide frequency separation between the Tx and Rx bands, a larger $K^2$ is of primary importance. A rotated Y-cut of the LiNbO$_3$ substrate has recently received much attention for use in the development of wideband filters because of its extremely large $K^2$ for shear-horizontal (SH) SAW. The combination of this substrate with a SiO$_2$ overlay has also been discussed for TCF improvement.

However, certain number of unwanted spurious responses. They are categorized into two types; one is caused by the Rayleigh mode and the other by the transverse mode. This paper describes the novel spurious suppression technique for SiO$_2$/Al/LiNbO$_3$ structure.

2. SAW resonator on SiO$_2$/Al/LiNbO$_3$

The SAW resonators were fabricated on a SiO$_2$/Al/LiNbO$_3$ structure, and their performance was evaluated. Figure 1 shows the input admittance $Y_{11}$ of the SAW resonator with $\theta=5^\circ$. The horizontal axis is normalized by the frequency at resonance. Here, the IDT pitch and SiO$_2$ thickness were set at 1 µm and 400 nm. The Al electrode thickness was 100 nm. As shown Fig.1, the Rayleigh mode spurious occurs at lower frequency side from resonant frequency. And, the transverse mode spurious occurs between resonance and anti-resonance frequencies. For applying the SAW resonator on a SiO$_2$/Al/LiNbO$_3$ structure to the duplexers, it needs to suppress both Rayleigh mode and transverse mode spurious.
3. Suppression of Rayleigh mode spurious

Figure 2 shows a cross-sectional view of the SiO₂/Al/LiNbO₃ structure. Above the IDT electrode, the SiO₂ overlay is usually deposited in a trapezoidal shape (see shape for Condition (a) in Fig. 2) by the successive sputtering of SiO₂. Controlling the sputtering condition[4], one is able to reduce the width of the trapezoidal region (see shape for Conditions (b) and (c) in Fig. 2), while keeping the height of the region almost constant.

It was then investigated how the Rayleigh-mode spurious response depends on the average width of the trapezoidal region. In the experiment, p, θ, hₐl and hₚₜₐₙ are, respectively, 1 μm, 5°, 0.08 λ, and 0.2 λ. The numbers of IDTs and reflector electrodes are 121 and 10, respectively, and the aperture length is 40 μm. Here, The IDT was apodized to suppress the transverse-mode spurious.

Figure 3 shows the change in the transmission characteristics (S₂₁) with the sputtering conditions. The average width of the trapezoidal region decreases in the order of Conditions (a), (b), and (c). For Condition (a), the upper base width of the trapezoidal region is almost the same as the electrode width, and the lower base width is larger than the electrode width. For Condition (b), the upper base width is smaller than the electrode width. For Condition (c), on the other hand, both the upper and lower widths are smaller than the electrode width.

As can be seen in Fig. 3, the spurious level due to the Rayleigh-mode decreases with the average width of the trapezoidal region; the dip caused by the Rayleigh-mode reaches almost zero for Condition (c).

Figure 4 shows the admittance characteristics of the resonator for Condition (c). The frequency separation between resonance and anti-resonance is large (circa 110 MHz). This corresponds to coupling coefficient of about 15%, which is sufficiently high for the current purpose. In addition, TCF is improved to be about –30 ppm/°C. In fact, the K² of the bare 5°Y-cut LiNbO₃ substrate is about 30% and decreases with the use of a SiO₂ overlay. Compared with that in the case of the bare LiNbO₃ substrate, however, a controlled width of the trapezoidal region is capable of suppressing the Rayleigh-mode spurious response and improving TCF. This means that the performance of a SAW resonator with a controlled width of the trapezoidal region is sufficiently applicable to a 3GPP Band I SAW duplexer.

Figure 3. Effect of cross-sectional shape of SiO₂ overlay on the transmission characteristic S₂₁.

Figure 4. Admittance characteristic of resonator fabricated using sputtering Condition (c).
4. Suppression of transverse mode spurious

The transverse mode spurious could be suppressed by using the apodized IDT. However, the insertion loss of the SAW resonator was degraded by decreasing $Q$ factor. We propose a new technique to suppress the transverse mode spurious on the SiO$_2$/Al/LiNbO$_3$ structure. A new technique to suppress the transverse mode spurious appearing in the SAW resonators on the SiO$_2$/Al/LiNbO$_3$ structure. In the technique, the dummy electrodes are only length-weighted in the form of a triangle,[12] which selectively scatter higher-order transverse mode spurious. In addition, the SiO$_2$ overlay is selectively removed from the dummy electrode region for enhancing the SAW energy confinement in the active electrode region.

Figure 5. The schematic view of the scattered dummy electrode weighting. (a) and (b) are a top view and a sectional view, respectively.

Figure 6 shows the schematic view of the scattered dummy electrode weighting. In Fig. 6, (a) and (b) are a top view and a sectional view, respectively. In the dummy region, the dummy electrodes are only length-weighted in the form of a triangle. Furthermore, the SiO$_2$ film on dummy region is removed. The SiO$_2$ film is only covered the interdigital region. Figure 7 shows the characteristics of the SAW resonators. In Fig. 7, the dashed line shows the characteristics of the SAW resonator with the non-apodized IDT. The transverse spurious could be completely suppressed. And, the minimum insertion loss of 0.18 dB is achieved, the value of which is just the same as one of SAW resonators with the non-apodized IDT.

5. Characteristics of the SAW duplexer

A miniature W-CDMA SAW duplexer in the 2GHz-band was fabricated on the SiO$_2$/Al/LiNbO$_3$ structure. The ladder topology was employed for both the Tx and Rx filters. The filters are adopted the scattered dummy electrode weighting to suppress the transverse mode spurious. A multilayered structure of AlMgCu/Ti was employed as the electrode material,[13] and sufficient power durability was achieved for use as the duplexer.

Figures 7 and 8 show the transmission characteristics from the Tx to ANT ports and from the ANT to Rx ports, respectively. It is seen that sufficient performance is achieved for the current application: the Tx to ANT insertion loss and suppression in the Rx band are 1.2 dB and 45 dB, respectively, for the Tx filter, while the ANT to Rx insertion loss and suppression in the Tx band are 1.9 dB and 51 dB, respectively, for the Rx filter. Figure 9 shows the isolation between the Tx and Rx ports. Sufficient isolation levels of 53 dB and 45 dB are obtained for the Tx and Rx bands, respectively. Owing to the SiO$_2$ overlay, the TCF was improved from –80 ppm/ºC, which LiNbO$_3$ substrates originally have, to about –30 ppm/ºC.
6. Conclusion

The Rayleigh mode could be suppressed by controlling the SiO2 shape of the SAW resonator on the SiO2/Al/LiNbO3 structure. And, the transverse mode spurious could be suppressed by using the scattered dummy weighting technique. The techniques were applied to the W-CDMA SAW duplexer. The SAW duplexer has excellent performances of low insertion loss, high attenuation and small TCF. And, the size of the SAW duplexer could be miniaturized to 2.5 mm×2.0 mm.

References


