Low Loss and High Isolation Techniques for High Power RF Acoustic Devices

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Abstract — Requirements for radio frequency (RF) devices in mobile phones have been getting more stringent, especially in multiband / carrier aggregation systems constructing many RF components. In this paper, we discuss two important items for RF acoustic devices developed by our team. First, we introduce the heat radiation effect and temperature compensation technology to suppress the temperature drift of acoustic devices for lower insertion loss. Heat sink effect of substrates and package, and temperature compensated film bulk acoustic resonator (FBAR) devices employing SiOF is introduced. Then, how to suppress the signal leakage from transmission (Tx) to reception (Rx) of the duplexer using signal cancellation technique is discussed, and SAW Band 8 duplexer is demonstrated as an example.

Index Terms — SAW, BAW, FBAR, duplexer, insertion loss, temperature compensation, TCF, isolation.

I. INTRODUCTION

The performances of radio frequency (RF) surface acoustic wave (SAW) filters and duplexers have been improved remarkably[1-5], and they are now widely used in the mobile communication market. RF bulk acoustic resonator (BAW) filters and duplexers based on film bulk acoustic resonator (FBAR) or solidly mounted resonator (SMR) technologies are going to penetrate into this market because they can be feasibly used in the multi-GHz range[6-9].

Requirements being placed on these devices are becoming more and more stringent every year. In addition to very low insertion loss and high isolation between transmission (Tx) and reception (Rx) in a band and between each bands so that they can be used in multiband and/or carrier aggregation systems shown in Fig.1. Power level from power amplifiers is expected to be increased because of many components on signal lines. Therefore, countermeasures for high power handling and signal leakage become very important.

In this paper, we focus on two significant issues. One is an acoustic device loss caused by temperature drift. The other is how to suppress the signal leakage. There are some approaches to improve insertion losses of acoustic devices. For example, reduction of electrical and acoustical losses, enhancement of filter design and suppression of temperature drift. It is crucial to consider the heat radiation of acoustic devices and temperature compensation (TC) technique to suppress temperature drift for lower insertion loss and avoid the degradation of power handing capability. Silicon for BAW/FRB, sapphire for TC-SAW[3], and metal package working as a heat sink plays an essential role in high power application[16,17]. TC-FBAR employing SiOF film is much attractive to improve TCF, which can also keep better coupling factor than that of SiO2 based TC-FBAR[13-15]. To suppress signal leakage, we have proposed a signal cancellation method between transmission (Tx) and reception (Rx) of a duplexer, called SUPERISOLATION [10-12]. Band 8 duplexer integrating cancellation circuit to suppress the Rx band isolation is introduced as one example.

II. LOSS REDUCTION BY SUPPRESSING TEMPERATURE DRIFT

A. Heat radiation

It is fortunate for FBAR and BAW devices to be able to use silicon as a substrate since it can provide fairly good heat conductivity. However, choices of substrate for SAW devices are limited. SAW devices using LiTaO3 (LT) or LiNbO3 (LN) have problem on heat radiation. And this can be known from Table 1. TC-SAW with LT/sapphire substrate fabricated using surface activated bonding can resolve the issue because a sapphire works as a heat sink. Figure 2 shows the temperature distribution in the SAW filter die when 0.8 watt of electric power were applied from the Tx port. These are thermal images observed using an infrared sensor. For a LT substrate, the heat generated in the Tx filter was confined within the Tx region and the maximum temperature was 100 degree C. However, for the bonded LT/sapphire substrate, the heat generated in the Tx filter dispersed throughout the die,
and the maximum temperature was less than 90 degree C. This is because of the larger thermal conductivity of sapphire. Thus, LT/sapphire can suppress heating and, as a result, temperature characteristics and power durability are improved.

Table 1 Properties of substrate

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal expansion [ppm/K]</th>
<th>Young’s modulus [GPa]</th>
<th>Thermal conductivity [W/mK]</th>
<th>Electric resistivity [Ωm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>4.5</td>
<td>66</td>
<td>1</td>
<td>10^12</td>
</tr>
<tr>
<td>Silicon</td>
<td>3</td>
<td>160</td>
<td>160</td>
<td>&lt; 10^12</td>
</tr>
<tr>
<td>Sapphire</td>
<td>5</td>
<td>470</td>
<td>42</td>
<td>&lt; 10^12</td>
</tr>
<tr>
<td>LT/AlO3</td>
<td>16.1</td>
<td>230</td>
<td>2</td>
<td>10^12</td>
</tr>
</tbody>
</table>

Figure 3 shows the package structure of Chip Size SAW Device (CSSD), and thermal analysis of CSSD and resin mold type package applying 0.8W to Tx port of duplexers. It is obvious that CSSD can radiate the joule heat from LT. We believe the silicon based BAW/FBAR, TC-SAW employing LT/Sapphire, CSSD structure and these combinations play an important role in higher power application.

Figure 2 Thermal analysis of SAW dies.
(a) LT-SAW, (b) LT/Sapphire-SAW

B. Compensation of temperature drift

In this part, we introduce our temperature compensation technology of TC-FBAR for high power application. We studied the layer structures based Mason model simulation to further enhance the K²eff for the TC-FBARs using the SiOF film. Normally TC-acoustic devices by using SiO2 depredate coupling factor.

In this work, the three structures shown in Fig. 4 were evaluated. For type A, the SiOF film was inserted into the center position of the AlN film. Type B and C were designed to kill the capacitance of the SiOF film. For type B, the Ru films were disposed on both sides of the SiOF film and were shorted. The SiOF film was inserted between the two Ru films in the bottom electrode side for type C. The film thicknesses were set so that the resonant frequency was approximately 1900 MHz and the TCF was approximately -10 ppm/oC. Figure 4 (b) shows the TCF and K²eff of these TC-FBARs. We determined that type C was the most appropriate for enhancing the K²eff.

We fabricated the TC-FBAR with type C. The experimental results of Smith chart, TCF, and K²eff of this TC-FBAR are shown with the simulated result in Fig. 5. The experimental result was the TCF of -11.1 ppm/oC and the K²eff of 6.26%. The TC-FBAR with type C was verified that it was obtainable to have the large a K²eff. This technique is definitely much attractive in current and future RF part in mobile systems.

Figure 4 TC-FBAR structure and simulation results of TCF and K²

Figure 5 Impedance performance of TC-FBAR

Next, we demonstrated TC-FBAR Band 7 filter by equivalent circuit model simulation based on actual resonator performances and compared with conventional FBAR filter. The passband performances of the TC-FBAR and conventional FBAR are shown in Fig. 6(a) and (b), respectively. Here, the performances under temperatures of -35deg C, 25deg C, and 85deg C are overwritten. As shown in Fig. 6 (a), the large K²eff for this TC-FBAR ensured the good passband performance. Coping with both low insertion loss
(IL) at the left passband edge (2500 MHz) and high attenuation at the right WiFi band edge (2483.5 MHz) was a critical issue for the Band 7 Tx filter. Results in Fig. 6 indicated that the improvement in the TCF for the TC-FBAR effectively suppressed the performance deterioration against the temperature change.

III. HIGH ISOLATION TECHNIQUE

Firstly, let us discuss the Tx signal flow to investigate the factor limiting the isolation of the duplexer. The Tx signal mainly flows to the antenna, however, some of the Tx signal leaks into the Rx side in an actual duplexer, because of the finite impedance ratio between the antenna port and Rx side in the Tx band. This is the Tx leakage via the signal line, which causes limitation of the isolation of a duplexer. In addition, there is another leakage, which is not via the signal line, but is caused by electro-magnetic coupling, electro-static coupling, imperfect grounding, and so on. Due to the existence of these two leakages, the isolation of conventional duplexers has been limited about 50 to 55 dB.

The proposed duplexer has a cancellation circuit, as shown in Fig. 7. In this circuit, the Tx leakages are cancelled out by the signal which flows in the cancellation circuit. Once the cancellation is achieved, the total Tx leakage vanishes and a high isolation can be obtained. By using this principle, we demonstrated the enhancement of Rx-band isolation in SAW Band 8 duplexer. Figure 8 shows the frequency responses of the fabricated duplexer. The improvement in the Rx-band isolation was about 10 dB without a degradation of insertion loss.

IV. CONCLUSION

In this paper, firstly we discussed insertion losses of acoustic devices caused by temperature drift and proposed how to suppress the joule heat and TCF. We expressed the importance of silicon for FBAR/BAR, sapphire substrate for TC-SAW, and then metal seal type package. TC-FBAR using SiOF with better coupling factor and TCF than those of SiO2 based TC-FBAR was proposed as well. Secondly, SUPERISOLATION technique was demonstrated by using SAW Band 8 duplexer. We could introduce improved isolation about 10 dB without degradation of insertion losses. We believe these approaches presented in this paper are very important for current and future multiband/CA mobile systems.

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REFERENCES


