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Spurious Mode Suppression in I.H.P. SAW Resonator using High Velocity Film on Glass Substrate

ガラス基板上の高音速薄膜を用いた I.H.P. SAW 共振子
における スプリアスモード抑制

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1. Introduction

Recently rapid increase of mobile data traffic and higher speed data rate are required for mobile communication systems. Carrier Aggregation (CA) in LTE-advanced is an essential technology for widening the operation bandwidth by combining two or more frequency channels. FDD (Frequency Division Duplex)-CA system requires multiplexers based on micro-acoustic resonators with low losses in pass band and without out-of-band spurious responses.

I.H.P. SAW (Incredible High-Performance SAW)[1] devices, employing an ultra-thin $LiTaO_3$ (LT) crystal on a support substrate with acoustic reflection layers, have been reported as a very high Q acoustic resonator owing to the excellent acoustic energy confinement. However, out-of-band responses are seen since spurious plate modes are also confined in some cases.

While a multilayer sturucture for the out-of-band spurious rejection is reported [2], using a Quartz with a specific orientation as the support substrate, such an appropriate material is limited. In this study, we propose an alternative approach using a combination of isotropic materials for the spurious suppression by optimizing the thickness of a high velocity film on a low velocity substrate.

2. Analysis of LT/SiO_2/SiN/Glass Structure

I.H.P. SAW and these kinds of multilayer SAW devices, materials with higher velocity bulk wave are required to attain high Q. If the speed of bulk wave in the layer is larger than the maximum speed of an elastic wave in the propagation direction, the wave of interest is totally guided throughout the stopband.

The simulated characteristics of a multilayer structure using the ultra-thin LT with a high velocity Aluminum Nitride (AlN) film on a low velocity glass substrate are already reported [3]. However, acoustic energy is apparently leaked into the substrate around the parallel resonant frequency even though the bulk wave velocity of AlN is fast enough to guide the Shear Horizontal (SH) wave in the LT. On the other hand, in the case of utilizing Si substrate (i.e. the high velocity layer thickness is semi-infinite), the SH wave is completely guided. The implication is that these high velocity materials have the threshold thicknesses for perfect guiding of leaky portion. Therefore it is beneficial to find an optimal thickness for confinement of the main mode maintaining the spurious plate modes leaky. For this approach, since the energy confinement of the spurious modes is affected by the velocity of the bulk wave in the support substrate, it is suitable for the support substrate having much slower bulk wave than that of the Si. From this viewpoint, we adopted two isotropic materials, Silicon Nitride (SiN) and silica-glass, as the high velocity film and the support substrate, respectively.

A 2D 1-pair electrodes model is shown in **Fig. 1** for Finite Element Method (FEM) calculation. This model is constructed by a couple of Al electrodes and a layered 50°Y-X LT/SiO_2/SiN/glass substrate. The thickness of LT layer and that of SiO_2 layer beneath were set to the same 30% of the IDT

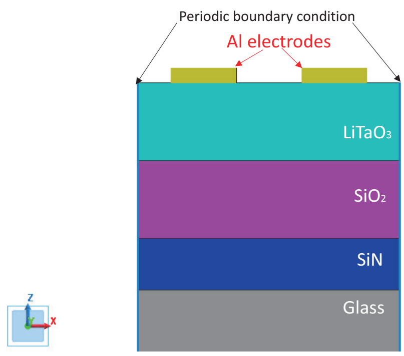

Fig. 1 Simulation model for 2D-FEM.

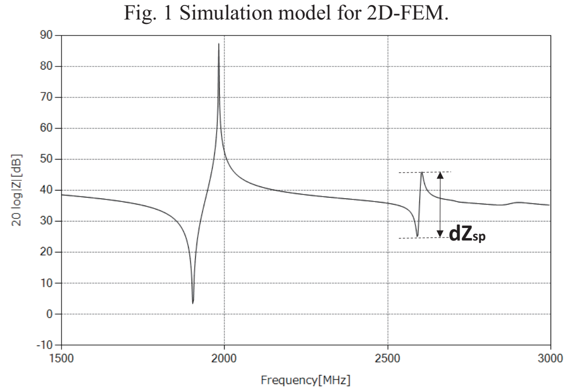

Fig. 2 Simulated impedance characteristics.

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wavelength. In this simulation, material losses of each layers are fitted to the measurement data of optimized resonators with the "double-layer" structure [1].

An example of simulated impedance 20log|Z| is shown in **Fig. 2**. A spurious Lamb mode response is seen above the main resonance. The impedance ratio of this response dZ_{sp} is used to evaluate the spurious mode level in this study.

Calculation data of maximum Bode Q [4] and dZ_{sp} of the Lamb mode response with the variation of SiN thickness are shown in **Fig. 3.** The SiN thickness is normalized by IDT wavelength. In this case, the thickness of about 80% of lambda is a threshold value in terms of Bode Q saturation, and the thickness range from 40% to 90% of lambda (hatching part in Fig. 3.) is "Sweet spot" enjoying high Q over 3000 and suppressing the spurious level below 10 dB.

3. Experimental Results

We fabricated a one-port SAW resonator using a SiN/glass substrate based on the analysis in Sec.2, and the other resonator using a SiN/Si substrate for comparison. The thicknesses of SiO_2 and SiN were about 34% and 45% lambda, respectively. The other geometries of the layered substrates were set to correspond with the simulation model in the previous section.

Figure 4 compares the measured impedances and Bode Q's for these resonators. Both resonators have a few out-of-band spurious responses, however, reduction of these responses level are shown in glass substrate compared of counterpart of Si. The nearest spurious response's dZ_{sp} is about 3.8 dB for glass and 7 dB for Si case. Regarding to the Bode Q, it deteriorates in the new structure compared with that in the Si substrate. However, the new structure is designed in the SiN thickness of 45% and is not optimized in terms of Q in Fig. 3. Since the degradation of the Q in the new structure is well predicted in Fig. 3, high Q of 4000 keeping the low spurious response is achievable, given that the optimized SiN thickness of 80% is applied.

4. Conclusion

In this study, we have demonstrated a new structure of I.H.P. SAW using a combination of a high velocity SiN film with a low velocity glass substrate. The FEM calculation reveals the relationships between thickness of the high velocity film and acoustic energy confinements for a main mode and spurious modes respectively. Based on the analysis, high Q of approximately 3000 and the level reduction of out-of-band responses are achieved simultaneously. This approach could effectively improve the out-of-band performance of layered SAW devices for multiplexer applications.

References

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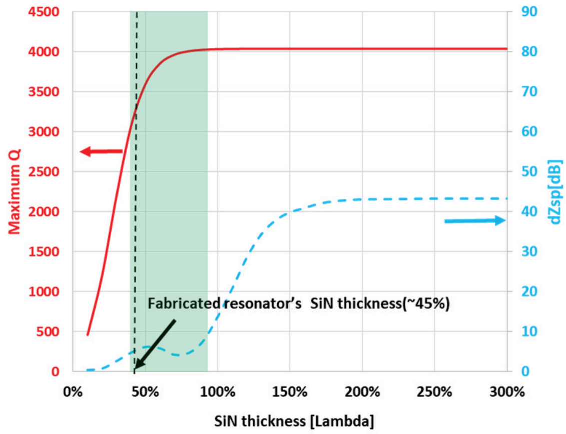
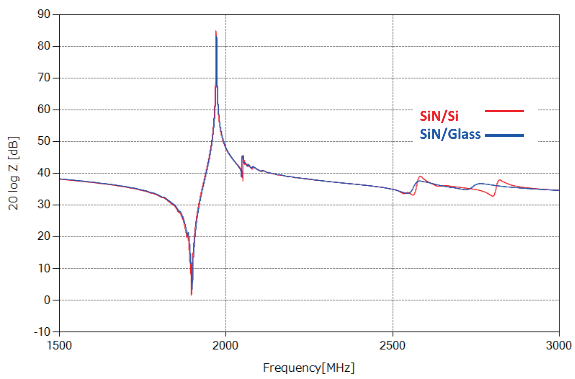
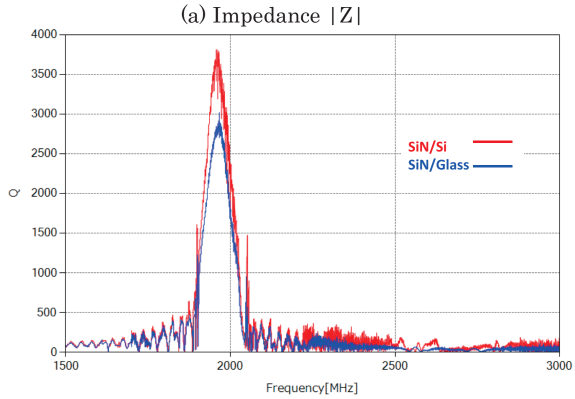


Fig. 3 Simulated variation of maximum Q and impedance ratio of spurious response with thickness of SiN layer on glass substrate.



(a) Impedance |Z|



(b) Bode Q

Fig. 4 Measured characteristics of fabricated resonators