Manufacturing and Performance Considerations for Thin Film Bulk Acoustic Resonator (FBAR) USPCS Band Duplexers

White Paper

Abstract

A manufacturing process flow and test data for a thin Film Bulk Acoustic Resonator USPCS band (1.9 GHz) duplexer is presented. The devices exhibit typical insertion loss of ~1.8 dB for Tx/antenna and ~2.2 dB for Rx/antenna paths. Isolation performance of ~ -42 dB in the Rx band and ~ -53 dB in the Tx band are also demonstrated for the technology. A 10 MHz roll-off from pass-band to stop-band accommodates frequency variations with temperature and allows for reasonable process margins.

Introduction

Although deceivingly simple, the suspended membrane FBAR device is not trivial to manufacture. Care must be taken to ensure that the key variables, such as the center frequency, acoustic coupling constant, electrical and mechanical Q, as well as structural concerns (including thin film stresses) are carefully controlled. All these variables must be managed to optimize performance, reliability and process throughput.

Fabrication Process Flow

A basic process flow for making the FBAR duplexers is shown in Figure 1. The first step is to prepare the silicon substrate; the surface must be prepared to permit the release of the FBAR membrane.

Adjusting the thickness of the thin film acoustic stack in Tx and Rx wafers provides the appropriate microwave response. A cross-section of a resonator membrane is shown by Figure 2. The basic Metal-Piezoelectric-Metal stack (MPM) cross-section and equivalent circuit has been described in a previous publication [1].

Two critical parameters, the center frequency and the effective acoustic-coupling constant are affected by the thickness of the MPM stack. For a typical process, a stack thickness of about 2 microns may resonate at ~2000 MHz. Therefore, a ~0.5% variation in the thickness of the films may change the frequency ~10 MHz. Even for the best VLSI processes, a 6σ thickness variance across a wafer, and from wafer to wafer, of <0.5% is (at best) very difficult to achieve. Therefore, special deposition capabilities have been developed to enable better thickness (frequency) control. In reality, variances of less than 4 MHz (~0.2%) are required across a wafer since thermal variations in frequency (as much as ±3 MHz) must also be taken into ac-

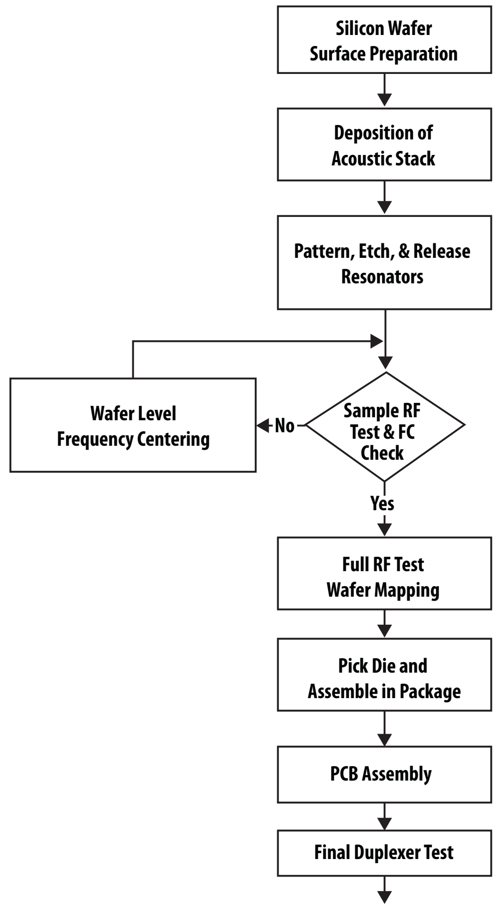

Figure 1. Basic Process Flow for FBAR Duplexer.

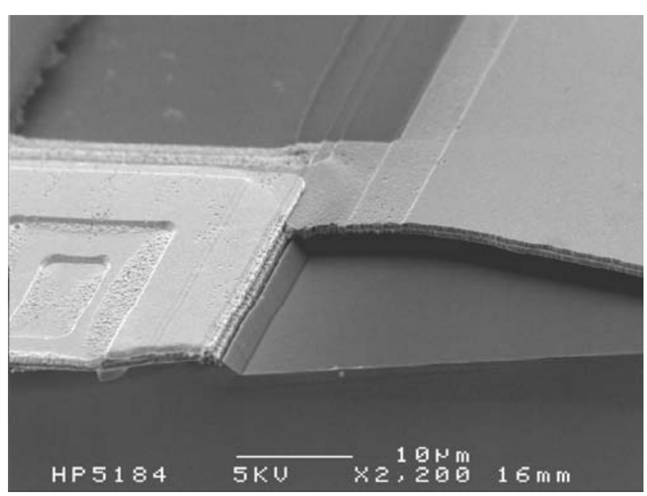

Figure 2. Cross Section of Bulk Acoustic Resonator.

count when trying to exceed the pass-band to stop-band USPCS specifications. In addition to the tight thickness control, the structural integrity of the membrane must be able to sustain high thermal/electrical stresses. For a better review of FBAR power and thermal issues, please refer to reference [2].

Results

After release, each wafer is sample-tested (~50 sites) to determine its center frequency, the value of the Quality factor, the acoustic coupling constant kt^2, and other key parameters. A sample PCM data table for a Tx wafer is shown in Table 1. Zo is the impedance, Co and Cm are the plate and motional capacitances, kt^2 is the acoustic coupling coefficient, Rs is the series resistance, kQp is a figure of merit (believed to more accurately represent the intrinsic performance of a given MPM stack) and ML represents the 'mass loading' difference between shunt and series resonators.

A Frequency-Centering step is used to further adjust the distribution across a wafer. The process is capable of moving the frequency up or down 2 to 20 MHz with little or no impact on basic resonator/ filter performance. A sample histogram for this process is shown by Figure 3.

Following this step, the wafers are fully RF tested, mapped, singulated and moved into the package assembly area, where each filter is placed inside a 3 mm x 3 mm Leadless Ceramic Chip Carrier (LCC) package.

A sample distribution after the packaging step is shown by Figure 4.

The final step in the fabrication process is to integrate the packaged Tx and Rx filters on a PC board together with the required tuning elements to obtain the appropriate duplexer response. The passive elements on the PCB as well as the transmission lines effectively 'pull' the center frequency of the filters into alignment with PCS requirements.

Figure 5 shows the PCS-band frequency response for a sample of several hundred duplexers taken over a given manufacturing time window.

Table 1. Parametric Data for Sample Tx Wafer.

	Zo (Ω)	Co	Cm	kt^2	Rs (Ω)	KQp	ML (%)
Max:	49.6	1.6	41.6	2.98	1.3	24.7	1.7
Min:	50.4	1.7	43.2	3.09	1.4	27.4	1.7
Mean:	50.5	1.7	43.2	3.10	1.4	27.2	1.7
SDev:	0.6	0.0	0.7	0.05	0.1	1.7	0.0

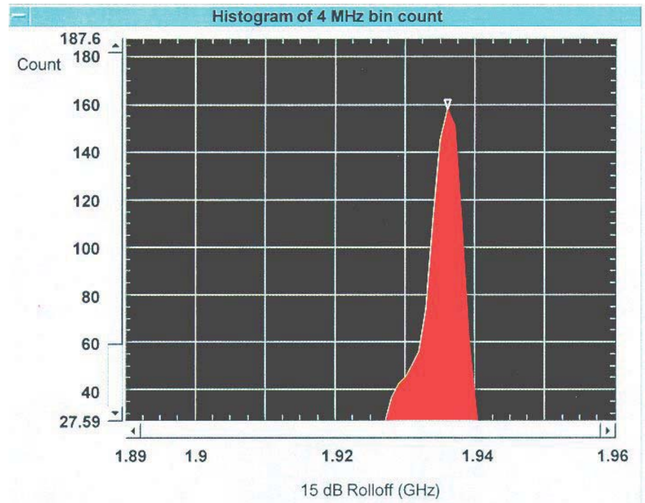

Figure 3. Sample Frequency Histogram After Frequency Centering Step.

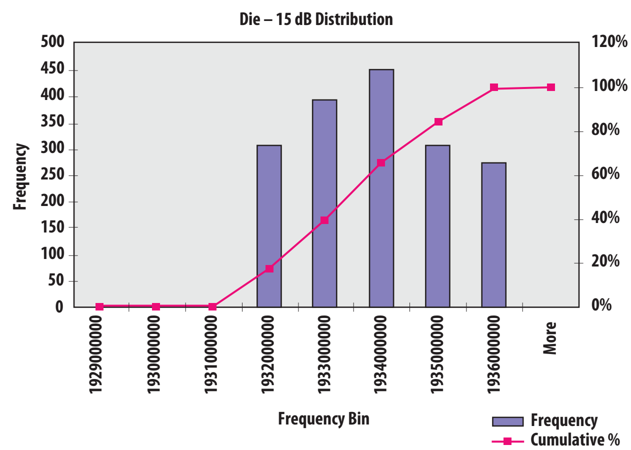

Figure 4. Frequency (-15 dB point) Histogram for a Sample Tx Wafer.

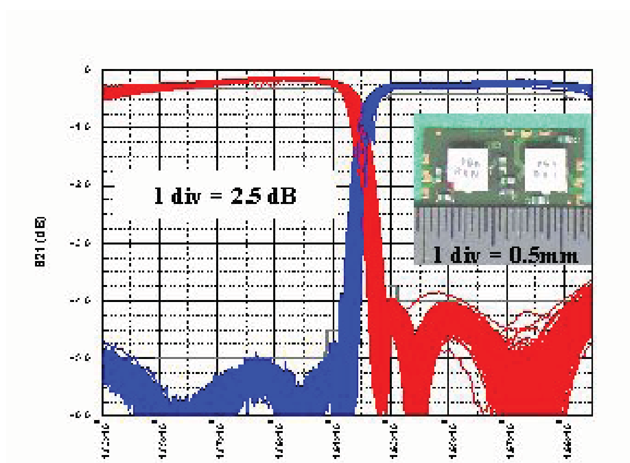

Figure 5. Performance of Several Hundred Duplexers Sampled from the Production Line.

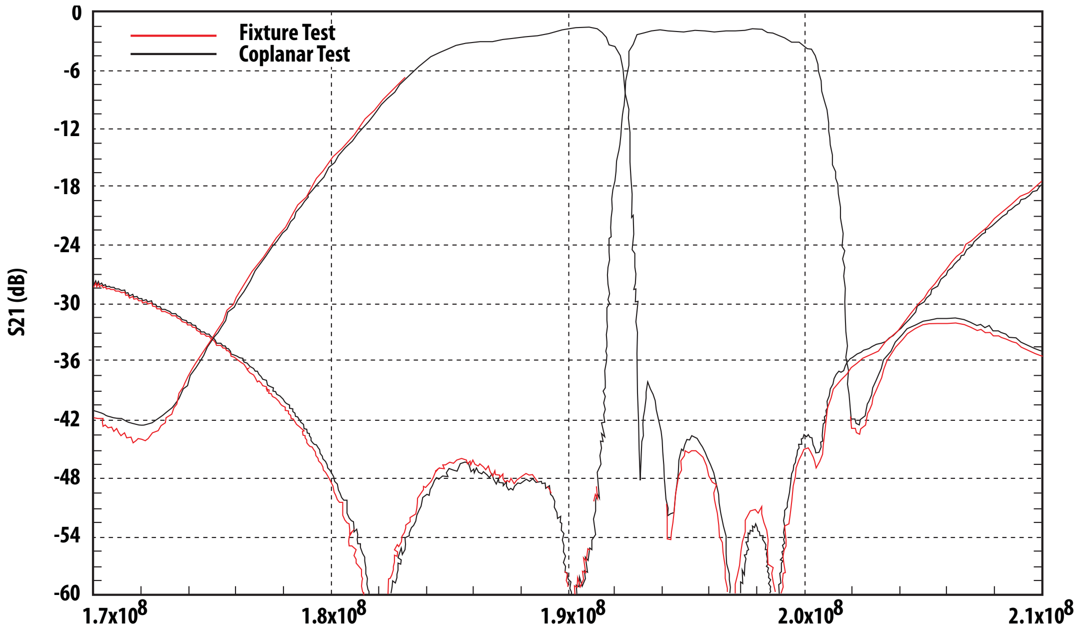

Figure 7. Comparison Between Tests Done Using a Contactor® and a Co-planar Strip Line.

Future Developments

Although reasonable performance can be obtained for an FBAR duplexer, there are several areas where improvements can be made. For example, using a 3D Maxwellian simulator, it is possible to better understand the effects of various parasitic elements on filter performance. By simulating an FBAR Rx filter inside the package (refer to Figure 6), it is possible to extract a multi-port S-parameter model and to better understand the effects of various parasitic elements on the rejection and the isolation performance.

The models suggest that it is possible to reduce (or cancel) the effects of various parasitic elements (particularly the mutual inductances between wire bonds) and obtain isolation performance similar to that of the non-packaged device from reference [1].

Further improvements can also be made in the area of duplexer testing. The requirements are simple: a test fixture capable of providing excellent repeatability, accuracy and isolation between ports over many test cycles. A specially designed RF Contactor® (a test fixture designed to fit the device under test with flexible Be-Cu contacts) allows testing of many thousands of the devices with the needed accuracy/precision. A special grounding scheme has demonstrated better than 72 dB isolation between ports. Figure 7 shows the response of a device tested using the contactor and re-tested on a stripline board using fully shielded SMA connectors. For additional perspectives on the subject of FBAR duplexer test, please refer to reference [3].

Finally, there is the opportunity to further simplify the duplexer product by eliminating the surface mounted components on the PCB (by embedding them in the printed circuit board). This is expected to improve the reliability (fewer components) and repeatability (tighter tolerance inductors) of the solution, while simplifying the manufacturing process.

Conclusions

This short paper has summarized the process flow and performance of FBAR duplexers fabricated under manufacturing conditions. Several areas for improving performance and manufacturability have been identified.

Acknowledgements

The authors wish to recognize the entire fab team at Avago Technologies' Wireless Semiconductor Division in Newark and Penang for providing extraordinary support for this work. The support from Albert Wang, Tom Lee, Bryan Ingram, Bill Sullivan and Ned Barnholt is also gratefully acknowledged.

References

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