BULK ACOUSTIC WAVE TECHNOLOGY ADVANCES

G. Fattinger*, R. Aigner, P. Stokes, A. Volatier, F. Dumont
TriQuint Semiconductor, Orlando, FL, (407)-598-3084
* eMail: gfattinger@tqs.com

Abstract – This paper focuses around two key aspects around recent advances in Bulk Acoustic Wave technology. The first portion discusses the impressive strides taken in improved electrical filter and duplexer performance. The second part deals with a reduction of the application foot print by means of introducing a wafer-level packaging approach, allowing flip-chip mounting of the SMR-BAW die. This renders bond wires surrounding the BAW die obsolete, and thus reduces the overall real-estate required in and application significantly.

I. INTRODUCTION

The growth-rate of RF-Bulk Acoustic Wave (BAW) technologies has outpaced the growth of the total RF-filter market by at least a factor of two during the past years. The reasons for this include the rollout of new bands in certain geographic regions, many of which are either above 2 GHz and/or in close proximity to other wireless bands and therefore very challenging to make. Band extensions – such as the band 2 → band 25 upgrade – have also proven to be a clear case where BAW is the best (or only) option.

While performance advantages have been (and will remain) the main reason BAW technologies are favored for certain bands, there is still a number of parameters for which customers expect to see improvements from one generation to the next generation of products. The most common expectation is a further reduction of insertion loss across the passband - and in particular at the band-edges - even when operating at elevated temperatures. In duplexers the rejection and isolation requirements become more stringent often in reaction to - or in anticipation of - new interference issues with bands that did not matter in the past. Non-linear effects have also become an item closely watched by all customers. The number of bands a future Smartphone will have to implement to support voice and high-speed data for worldwide roaming has grown beyond 10 bands. Considering the growing number of filters and other features packed into a phone, the size of each filter or duplexer needs to shrink significantly year over year.

Addressing these opportunities requires improvements in the following areas:

- Acoustic and electric losses
- Enhanced flexibility for filter design
- Space wasted by bond wires surrounding the BAW die

Naturally the market also demands products to be lower in price year after year. Fortunately increased manufacturing volumes and maturity of the BAW process, in addition to advances in filter design methodology and associated reduced real estate requirements, have resulted in significantly lower costs.

II. EVOLUTION OF BAND 2 DUPLEXERS

In the following section the evolution of BAW technology is demonstrated using the example of a band 2 duplexer. The parts in this study have been optimized for maximum performance in module applications. Thus the requirements have been not exactly the same as one would expect from a stand-alone duplexer. Nevertheless, this vehicle shows the impressive strides that have been taken in terms of performance over the last four years.

Insertion loss and skirt steepness were improved (see fig.1) by modifications in process flow, device geometry and selective reduction of effective coupling coefficient in certain resonators. This evolution of BAW technology is demonstrated using the example of a band 2 duplexer.

10
b

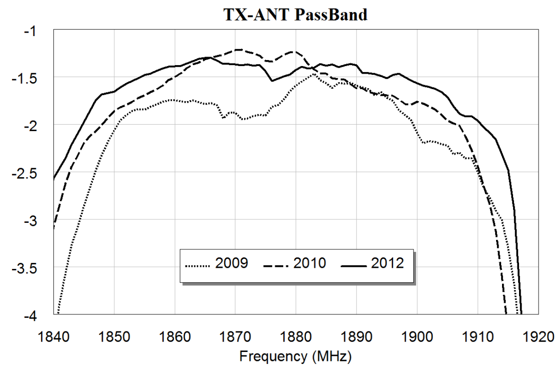

Fig. 1: Evolution of Band 2 duplexer Rx-Ant pass band characteristics over the past four years.

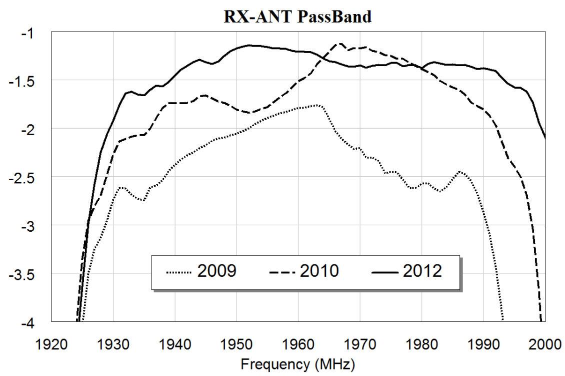

Fig. 2: Evolution of Band 2 duplexer Rx-Ant pass band characteristics over the past four years.

This development can be attributed on the one hand to significant improvements in resonator losses. Quality factors at anti-resonance have risen from a mere 1300 to 2500 and higher. On the other hand, filter design methodologies have advanced dramatically as well. MIM-capacitors, multiple resonator frequencies, are two of the most prominent items in this respect.

As a consequence of improved design, the locus size at the Tx input port of the duplexer has been shrunk dramatically as well (see fig. 2). This is especially important since in a real world application a duplexer will be fed by a power amplifier (PA). In order to achieve high PA efficiency (PAE) and linearity across the desired passband, the variation of the duplexer impedance needs to be as small as possible.

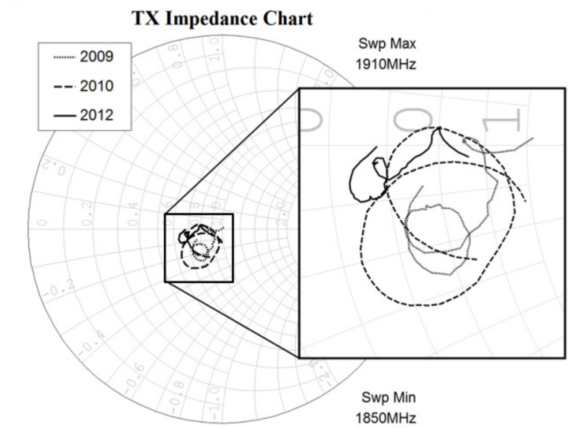

Fig. 3: Locus size improvements in the recent BAW duplexer generations.

Common understanding of ladder filters suggests that a certain minimum coupling coefficient k^2_{eff} for resonators is necessary to meet bandwidth and return-loss specifications for a given band. However, in some cases it would be most advantageous to reduce k^2_{eff} only on a subset of the resonators in the ladder because this allows improving slope steepness of the filters substantially.

The effective coupling coefficient of a BAW resonator k^2_{eff} depends on the purity and crystalline orientation of the grains in the AlN piezolayer [1] as well as the choice of materials and thicknesses of top and bottom electrode layers, reflector layer(s) and the passivation layer. Many possibilities exist to reduce k^2_{eff} but often other parameters such as Q-values or spurious modes will suffer as well.

One possibility to adjust k^2_{eff} of certain branches in a ladder filter is to attach a series or parallel capacitance to BAW resonators. This is a well known method [2] but only feasible if the capacitors are integrated on the BAW chip itself – otherwise the number of interconnects needed to attach external capacitance into the filter circuit will be difficult to justify.

TriQuint's SMR-BAW process had all layers needed for MIM-caps already in place so those caps don't add any costs whatsoever. Utilizing existing reflector layers as electrodes and dielectric layers in a 'reflector MIM-cap' has proven to work extremely well (see fig. 4). We first introduced them in large volume production in 2010. In fact those capacitors have very tight tolerances and ESD robustness is far superior to MIM-caps in CMOS or GaAs processes because the dielectric layer is extremely smooth, flat and fairly thick. The capacitance values typically needed for our purposes are below 1 pF (at 2GHz), therefore in many cases those MIM-caps fit completely below active resonators and don't even occupy additional space on the chip.

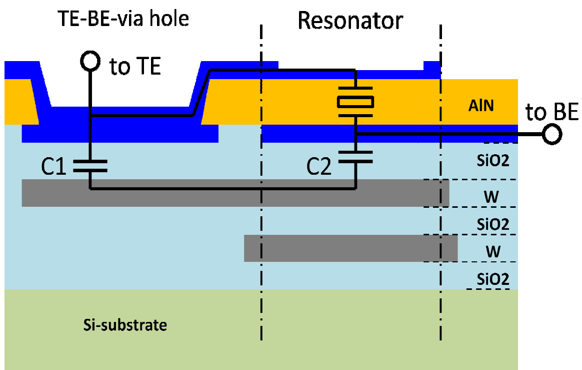

Fig. 4: SMR-BAW resonator in TriQuint's process with integrated 'reflector MIM-caps' C1 and C2 which enable effective coupling individually adjusted for each branch in a ladder filter.

The resistive losses in the MIM-caps are sufficiently low to be irrelevant for the total filter losses. Additional MIM-caps can be used to implement matching networks as the one needed at the antenna in a duplexer, thus eliminating the cost and space for discrete SMT capacitors which earlier products had to place inside the package.

III. WAFER LEVEL PACKAGING

Every year the semiconductor industry expects their products to consistently shrink. Partially this is driven by cost considerations, of course. Another component is the end-customer's demand for ever thinner, sleeker and lighter products.

In the following section of this article, a rather simple approach for Wafer-Level-Packaging (WLP) will be discussed, enabled by the inherent mechanical and environmental robustness of SMR BAW. Traditional wire bonding technology used to connect BAW filter die with their environment (e.g. multi-layer substrates) has become a major contributor to the final product size (see fig. 5).

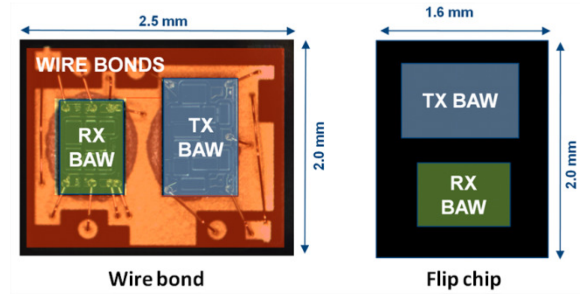

Fig. 5 Real estate requirements for a Band 2 duplexer, comparing wire bond to flip chip assembly.

The alternative approach featured in this article is based on creation of a cavity above the active area of the BAW die by means of a photo-sensitive epoxy material. Subsequent thermal cure of this material leads to a structural integrity that is able to withstand a typical high pressure overmold process with minimal deflection of the cavity's roof.

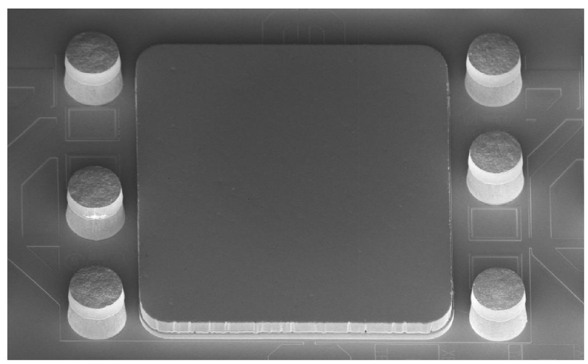

Fig. 6: BAW device after wafer-level package processing.

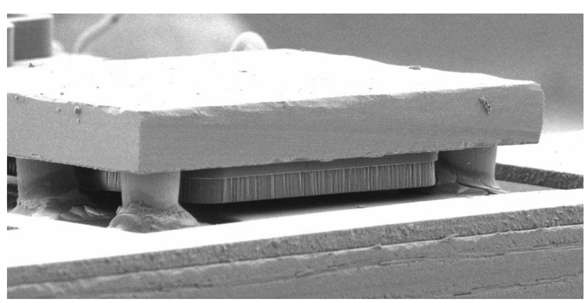

Fig. 7: BAW WLP part soldered on a substrate, before overmolding

In a second step, Cu/Sn pillars are grown next to the cavity. Their height is sufficient beyond the

10 b

cavity height to allow for flip chip mounting of the part onto a substrate, while maintaining enough stand-off to facilitate proper underfill. Fig. 6 shows a BAW device after wafer-level package processing has finished.

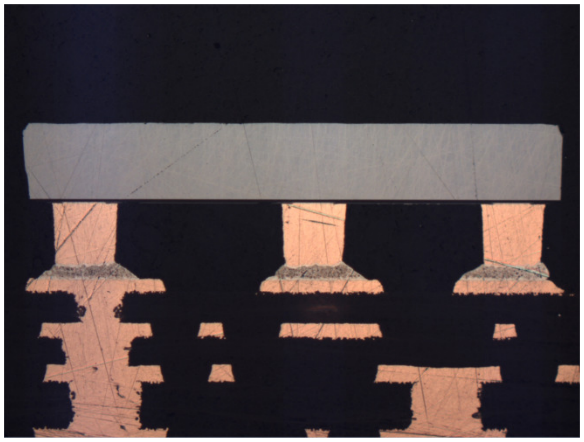

Fig.8: Cross-sectional image of a BAW WLP part soldered on a substrate and overmolded.

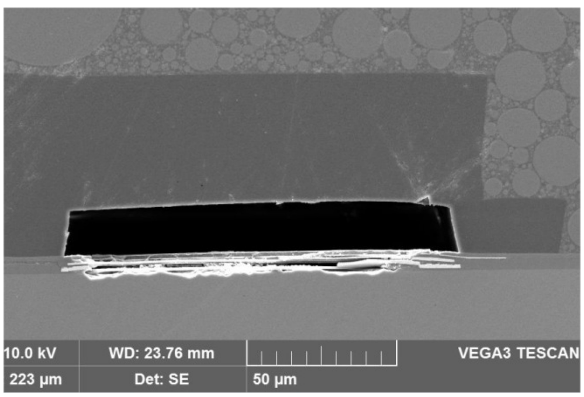

Fig. 9: SEM image of a BAW WLP cavity.This device has been flipped onto a substrate and encapsulated by means of high-pressure plastic overmold.

The same part after dicing and flip-chip mount onto a plastic substrate is shown in fig. 7 in a tilt-SEM image, while fig. 8 exposed the cross section of the Cu-pillar and solder joints to the plastic substrate.

Finally, in fig. 9 the cavity created over the active areas of the BAW device is shown. Note that the high pressure overmold process happening at approximately 750psi did not deform the cavity, thus protecting the device area perfectly.

VI. CONCLUSION

After a decade of commercial/high-volume production of BAW for RF filters skeptical comments about the importance of BAW for the future of wireless systems have become exceptionally rare. BAW technologies keep gaining market share, predomindantly in the premium filter segment and at high frequencies. As such they are subjected to fierce fights - in the marketplace, on the job-market and inside courtrooms. Opportunities ahead are plentiful but challenges are significant. Innovation and is key to stay ahead. The main advantage of BAW over competing technologies is founded in achieving substantially lower losses at very high frequencies; whereas the current state-of-art in BAW is not even close to true physical limits.

VII. ACKNOWLEDGEMENTS

The authors want thank the TriQuint process engineering team and the technician staff for their tireless efforts supporting BAW R&D.

REFERENCES

[1] RF-Bulk Acoustic Wave Filters for Communications, K. Hashimoto (editor), Artech House 2009, page 175-187

[2] US patent 6,653,913 B2, Nov. 25th, 2003 and prior art cited therein.

[3] Recent Advances in BAW Technology, R. Aigner, G. Fattinger, A. Volatier, F. Dumont, P. Stokes, 2012 International Symposium on Acoustic Wave Devices for Future Mobile Communication Systems, Chiba, Japan, Dec. 2012