Recent Advances in Bulk Acoustic Wave Filter Device Performance and Miniaturization

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Abstract

We report on two recent advances in Bulk Acoustic Wave (BAW) filter technology. First, we have made major electrical filter performance improvements by increased quality factor (Q), accomplished by resonator stack and geometry optimization. This technology development leads to ~0.5 dB improvement in filter insertion loss. Secondly, we have achieved a significant reduction (up to ~40%) in BAW die size by advanced packaging techniques, enabling overall application size reductions and cost savings.

INTRODUCTION

Mobile devices continue to demand more RF filter content year over year due to the increasing number of cellular bands and complexity (figure 1) [1]. SAW (Surface Acoustic Wave) and BAW filters are the technology of choice to address these bands, SAW typically addressing lower frequency bands ("Low Band"), and BAW addressing higher frequency bands ("Mid/High Band"). The need for high performance filters will not slow down in the future as 5G bands will soon be deployed in the coming years for higher data rates, for which BAW will continue to address at least the sub-6 GHz bands [2]. This huge demand drives rapid technology development in the filter space for both performance and size.

Due to the closeness of the cellular bands and multiplexing requirements ultra-high-performance filters with very steep skirts are required. To make steep transitions and reduce filter loss high quality factor (Q) is needed. Q is a measure of energy losses within the resonator which damp the resonance. We have recently improved our Q factor significantly by optimization of the resonator stack and geometry. Here we will show resonator and filter results from such optimization.

In addition to electrical performance requirements, rapidly increasing RF content requires major shrinkage of individual components in modules as more and more filters are being crammed in small footprints. BAW filter real estate can be separated into two components: (i) acoustic area which contain mainly resonator structures and (ii) non-acoustic structures which contain the micro-cavity packaging portion of the die to protect the resonator from packaging materials as

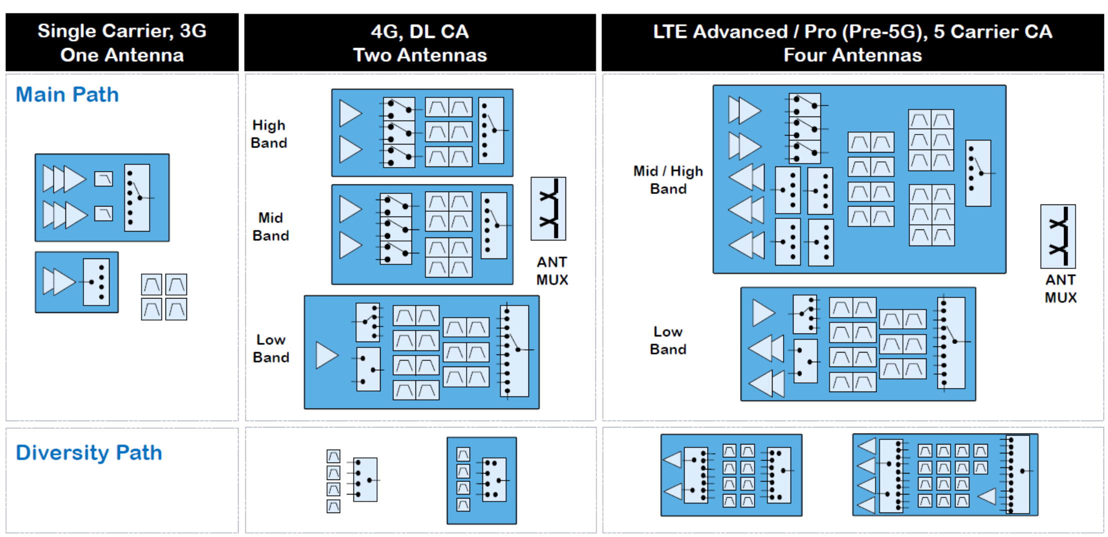

Fig. 1. Evolution of the RF front end. More and more filter functions are needed for the main path as well as the diversity path. Current modules can contain 20+ BAW dies [1].

well as make connections to the laminate substrate. Here we will focus on the latter packaging portion. Current WLP (wafer level package) micro-cavities can consume a significant amount of area, sometimes also called a WLP "house" made from permanent photo-definable dry film materials. The large area consumed by the house is partially related to cavity cap thickness requirement. The cap material must be relatively thick (~50um) to withstand high pressure overmold in packaging [3]. The thicker cap drives high aspect ratios for small lateral features and makes processability more challenging, therefore lateral dimensions are often grown for better processability. Additionally, connections to the laminate substrate are done through copper pillars outside the cavity which can also take significant space. We will discuss recent advances to shrink the thicknesses and lateral dimensions of the micro-cavity structure as well as reutilizing the micro-cavity wall and cap area as through-via for optimal use of interconnection space.

Q FACTOR IMPROVEMENTS

Figure 2a shows a cross section of a SMR (solidly mounted resonator) BAW device. A piezoelectric thin film AlN layer is sandwiched between two electrodes and is driven with an electric field and hence vibrates in the vertical direction. Alternating layers of low and high acoustic impedance act as an acoustic Bragg reflector to confine energy in the vertical direction. A thicker ring of material is defined around the resonator perimeter (called "border region") is used to confine lateral acoustic energy or mitigate acoustic leaking waves. We have reoptimized our reflector stack and border region to improve confinement and device response.

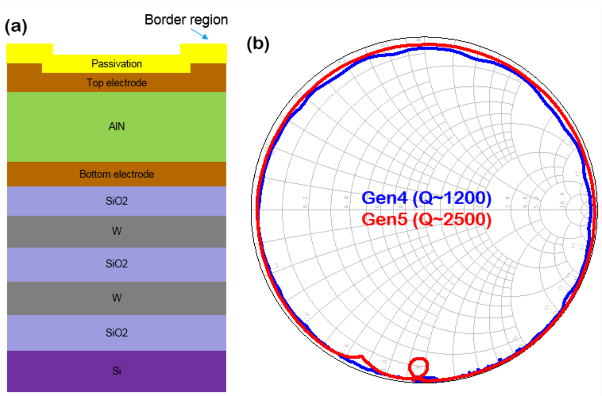

Fig. 2. (a) Cross section of a SMR BAW resonator showing a piezoelectric AlN thin film sandwiched between two metallic electrodes, Bragg reflector to confine vertical acoustic energy, and a border region to confine lateral energy. (b) Smith chart comparison showing previous technology (Gen4, blue) vs. new technology (Gen5, Red). Significant improvement in Q and spurious modes is seen here.

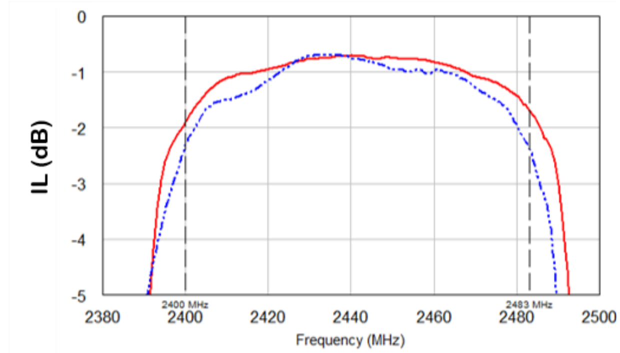

Fig. 3. Previous (dashed blue) vs. new generation (solid red) filter pass band performance for Wifi filters. Significant improvement at the bad edges are seen here (~0.5 dB).

Figure 2b shows a smith chart comparison between previous generation (Gen4) and new generation BAW resonators (Gen5). The overall Q value is improved by more than a factor of two and spurious mode content is greatly reduced. Figure 3 shows a comparison of Gen4 vs. Gen5 Wifi filters showing significant improvement in Insertion Loss (~0.5 dB) at the band edges. This significant improvement in resonator and filter performance is necessary for next generation mobile applications.

DIE SHRINK

Figure 4a shows a simplified picture of a Qorvo WLP BAW die. The non-acoustic area is made up of probe pads, outer and inner walls of the micro-cavity, and Cu pillar interconnects. The acoustic part of the die area is made up of the resonators themselves. Wall and cap layers are made from permanent photo-definable dry film materials and Cu pillars

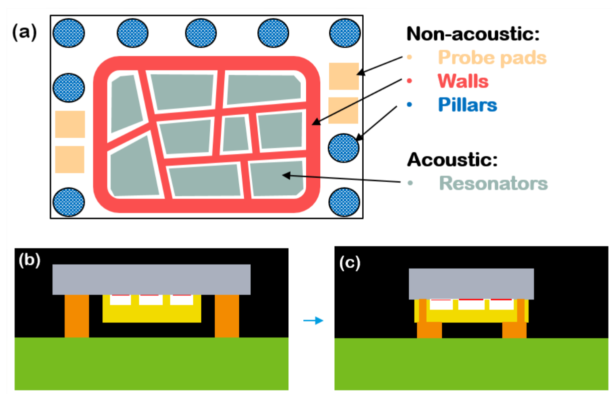

Fig. 4. (a) Simple top down schematic of Qorvo WLP BAW die. (b) Flip chip WLP BAW die (gray) with Cu pillar (orange) and WLP cavity made from photo-definable dry film resist (yellow). (c) Next generation BAW package where via through dry film material is utilized to minimize non-acoustic area.

are fabricated through an electroplating process. It can be seen here that a large part of the non-active area is from the Cu pillars. In next generation packages we fabricate the interconnection through the wall and cap layer which is a more efficient utilization of already existing non-active area (figure 4b and 4c). For future generation packages we also choose a thinner cap material. Reduction in cap thickness allows for better processability of the via (example: cap lithography, seed layer deposition and plating resist lithography) and better mechanical reliability. Reduction of the cap thickness also requires reduction of the overall mold pressure in assembly since the deflection of the cap in molding is proportional to the pressure and it is critical that the cap does not deflect significantly during the molding process [3]. Finally, inner wall width is reduced by a factor of two to reduce lateral space even further. These reductions overall lead to significant die space savings up to ~40% which is needed for future generation applications.

CONCLUSIONS

BAW devices with better performance and smaller size will be needed as RF front ends get more complex and contain more bands. Qorvo BAW technology is well positioned in terms of both performance and size to address this complex and growing market. There are still many challenges to address to further increase performance and reduce overall filter function area closer to fundamental limits.

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ACRONYMS

BAW: Bulk Acoustic Wave
SAW: Surface Acoustic Wave
WLP: Wafer Level Packaging
RF: Radio Frequency