Copy, Scale, Develop, and Match – A Methodology for 200mm Bulk Acoustic Wave Filter Production Line Start up at Qorvo

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Abstract

There are many different methodologies for a line startup, process transfer, and process upgrade. In our startup of 200mm Bulk Acoustic Wave filter line converted from the existing 150mm production line, a methodology of Copy, Scale, Develop, and Match (CSDM) is introduced. A difference FMEA (DFMEA) is used for the risk assessment. Both CSDM and DFMEA ensure the product performance of 200mm wafers matches to the one from the 150mm line.

Introduction

RF filter and duplexer market has been growing very fast in the past few years and will be continuously growing with the demand of fast growing smartphone market. A recent research forecasts the global radio frequency (RF) filter market to grow at a CAGR of 15.24% in the time frame of 2016 and 2020 [1], including a 30.86% CAGR for Bulk Acoustic Wave RF filter in the same period [2]. To meet this market demand, Qorvo decided to start a 200mm production line while the company continued the expansion of the existing 150mm BAW line in 2015.

In this paper, we will discuss the methodologies, difficulties, solutions, and results of the 150mm to 200mm conversion. Since there are many organizations involved in the line startup, such as tool purchase, facility modification, tool installation and qualification, process setup, manufacturing training, pathfinder and qual lot processing, and product reliability qualification, we will focus on the technical part in this paper.

Copy, Scale, Develop, Match

There are many different methodologies used for technology transfer, line start up, or line conversion, such as copy exact, copy smart, and copy smart exact, etc. In Qorvo Richardson fab, there exists a 150mm BAW production line. Therefore, the 200mm line setup is based on the existing 150mm production. The conversion methodology used is "Copy, Scale, Develop, Match" (CSDM).

To ensure the quality, we copied as much as we can from the 150mm BAW process. This Copy includes (1) the process flow; (2) the process control steps; (3) the process control limits; (4) the tool maintenance schedules; (5) tool qualification procedures, (6) tool automations, and (7) cross section profiles, etc.

However, for the 200mm line, there are two things unique or different from the 150mm line. First, the wafer area is almost double (1.78X). Therefore, the mapping in the in-line product monitoring and process/tool qualification needs to be scaled up per the wafer size. Also, certain control limits need to be normalized in order to share the same control limits between 150mm and 200mm process, Second, since the 200mm line has much lower volume at beginning comparing to the 150mm production line, some of the tool qualification frequencies need to be scaled down per loading for the cost reduction purpose.

Although the majority tools in 200mm line are the same as the ones used in the 150mm line, there are different types of tools, such as photo coaters, oxide etchers, ashers, and etc. Table I is a list of process and metrology tools used in the 200mm line. A conversion strategy is defined based on whether they are the same as 150mm production line and whether they are shared with 150mm wafer process or not. For processes with different types of tools, the processes have to be developed. Even with the same tools, the processes still require either more development or more fine tuning in order to achieve the same uniformity requirement.

TABLE I
EQUIPMENT USAGE AND CONVERSION STRATEGY

Tool Purpose	Tool Type	Tool Usage	Conversion Strategy
Process Tool	New for 200mm	200mm use only	Develop
Process Tool	Same as 150mm	200mm use only	Develop
Process Tool	Same as 150mm	Shared with 150mm	Scale
Metrology Tool	Same as 150mm	Shared with 150mm	Scale

All Copy, Scale, and Develop serve the same and only purpose: match the 200mm product performance to the 150mm line, including both electrical performance and application reliability.

Risk Assessment and Difference FMEA

The review of existing 150mm Failure Mode Effective Analysis (FMEA) gives the basic potential risk for the 200mm line. This focuses on the similarity or commonality between the 200mm and 150mm lines to avoid reinventing a wheel. To ensure 200mm line performs as well as 150mm line, a Difference FMEA is also developed for the 200mm line by specifically reviewing the tool and process differences from the 150mm process.

The designs of short loops, which will be discussed in the next section are based on both the common FMEA and the Difference FMEA developed for 200mm line. The requirements of the data collections from each short loop lot come from the risk assessment per FMEA analysis. No matter which conversion strategy, Develop or Scale, used per process tools, the required data has to be collected to match with the 150mm process. In this way, we have much higher confidence to process our full flow pathfinder lots and qualification lots.

Four Phases to Ensure CSDM

There are four phases in the conversion from 150mm to 200mm which is shown in Figure 1. The CSDM methodology is followed and verified through the four phases.

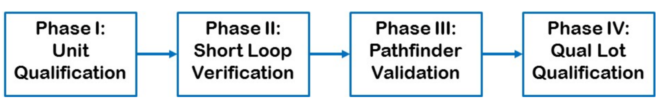

Figure 1. Four Phases of the 150mm to 200mm conversion

Phase I is the unit qualification for each individual tool release. In this phase, each process tool has to meet the fundamental tool performance requirements, such as film deposition thickness, uniformity, etch rate, photo CD, particles, etc. It is not an easy task to match the within wafer variation or range of the 200mm process to the 150mm tools, because of the large size of the wafers. Table II is a 200mm and 150mm CVD oxide film matching comparison as an example of CSDM confirmation.

TABLE II
CVD Oxide Comparison (A.U)

Item	200mm CVD	150mm CVD #1	150mm CVD #2	LSL	USL
Parameter 1	0.1	0.24	0.5	na	<1
Parameter 2	1.01	1	0.97	0.95	1.05
Parameter 3	0.67	0.23	0.45	na	<1
Parameter 4	-0.20	-0.34	-0.96	-1.02	1.02

Phase II is running short loop lots to check the potential integration issues. The whole process flow is broken into five process blocks with 33 sub-blocks. The short loops are designed to check the interactions between sub-blocks within a process block or cross blocks. The physical analysis, in line measurements, electrical tests are required for the 200mm and 150mm matching comparison. Table III is a partial list of the short loop designs as an example. Figure 2 is a step height comparison for the 200mm and 150mm matching. The chart in Figure 2b indicates a very good matching in the within wafer range between 200mm and 150mm.

TABLE III
Partial Short Flow Design and Requirement

Short Loop	Block	Routes	Purpose
SL 1	Block 1	Sub-block 3, 4, and 5	Film characterization
SL 3	Block 2	Sub-blocks 13 to 18	Pattern alignment and integrity
SL 7	Block 2 and Block 4	Sub-block 12, 26, and 27	Wafer handling
SL 10	Block 4	Sub-blocks 26 to 31	WLP integrity
SL 11	Block 5	Sub-block 32	Wafer finishing

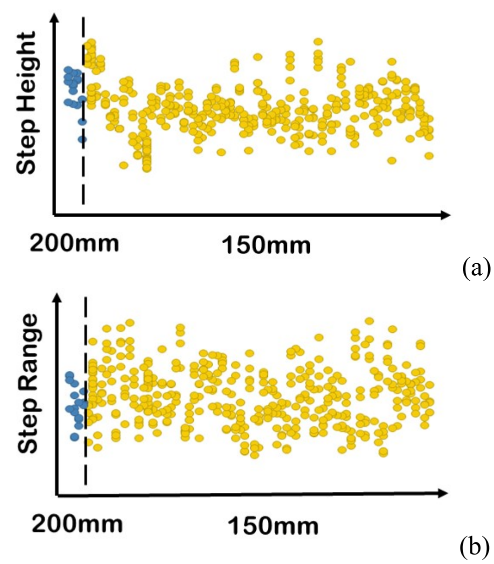

Figure 2. A step height matching between 150mm to 200mm. (a) Step height; (b) Step height within wafer range

Phase III is running pathfinder lots, which serve as the line minesweepers. This includes tool automation set up, operator training, SPC chart setup, in line data collection and feed through check, whole structure cross section for physical matching of layer thickness, etch profile, CD, and electrical measurement for part performance matching. The results will be feedbacked to each process for the final tuning before starting to run the qualification lots.

Phase IV is running lots for the process qualification. In this phase, all processes are approved by the technical review board and locked. Since it is possible that there are changes in the 150mm processes due to continuing improvement in the time frame between 200mm process setting up and starting qualification lots, a thorough review of 150mm process change history has to be performed for all processes to make sure the released 200mm processes catching up with the latest version of 150mm processes.

PERFORMANCE MATCH

The product final electrical and reliability performance matching is our final goal in the 150mm to 200mm conversion. To ensure this, multiple in line check points are inserted into the process flow, including not only the one existing in the 150mm process flow as regular process control, but also checks specifically for 200mm pathfinder and qualification lots. Figure 3 shows a schematic of simplified process flow with the check points and their purposes.

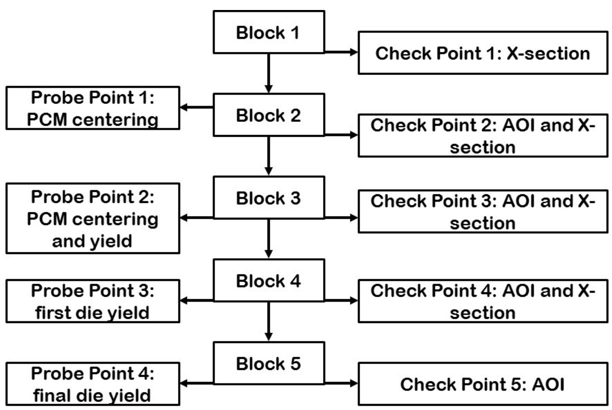

Figure 3. Simplified process flow with check points and their purposes

Figure 4 shows the frequency matching between the 200mm and 150mm lines at the first in line electrical probe step. The triangles on each side of data set indicate the frequency range and the 200mm range matches 150mm range very well.

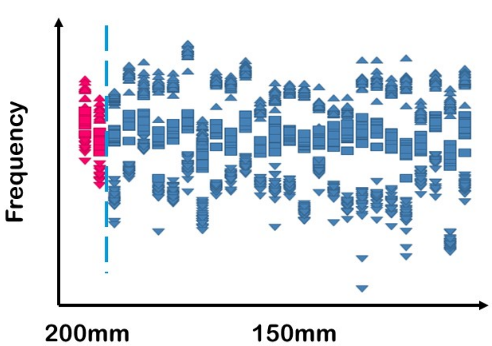

Figure 4. Frequency matching between 150mm to 200mm at the first in line probe step

Electrical die sort test is performed at the end of the process. Both die yield and parametric distributions are used for the matching comparison. As mentioned earlier, performance "match" is the goal of the 200mm conversion. Figure 5 is the die sort yield comparison of the first three 200mm pathfinder lots and the historical 150mm average yield and they match very well.

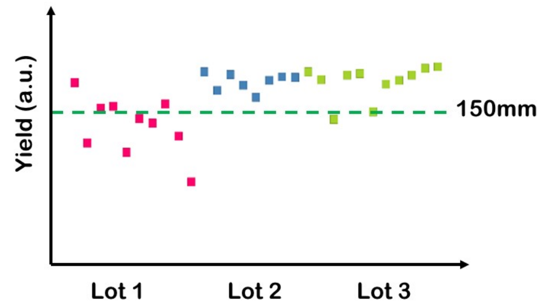

Figure 5. Wafer electrical die yield trend of the 200mm pathfinder lots (Square dots) vs the 150mm historical average (dotted line) for the same product.

The other important performance match is the product reliability performance with packaging. A standard reliability qualification is performed for the first pathfinder lot and the required qualification lots. This standard reliability includes 3X reflow, HTSL, uHAST, 85°C/85% RH, temperature cycling, and etc. Figure 6 is the performance comparison of one 200mm lot and one 150mm control lot pre and post a stress.

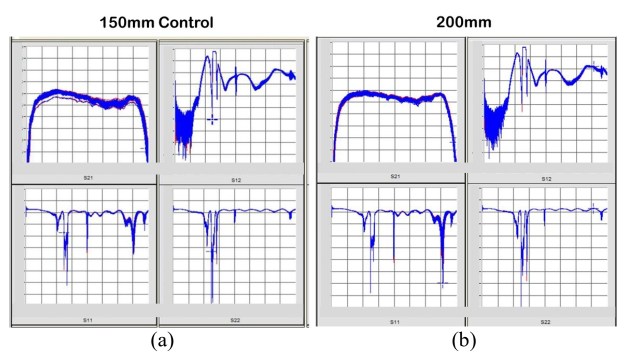

Figure 6. Pre and post stress RF performance comparison of one 200mm lot and one 150mm control lot

CONCLUSIONS

We successfully qualified a 200mm BAW production line based on the existing 150mm line at Qorvo. The methodology used for the 150mm to 200mm conversion is Copy, Scale, Develop, and Match. Both common FMEA and Difference FMEA are used for the risk assessment and the short loop designs. By using the CSDM methodology, we got the first full flow pathfinder lot with the yield in the par of 150mm.

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ACRONYMS

RF: Radio Frequency
BAW: Bulk Acoustic Wave
CAGR: Compound Annual Growth Rate
TRB: Technical Review Board
FMEA: Failure Mode Effective Analysis
HTSL: High Temperature Storage Life
uHAST: unbiased Highly Accelerated Stress Test
RH: Relative Humidity
CSDM: Copy, Scale, Develop, and Match