The Use of a Structured Approach to Solve Yield Limiting Defects in a Compound Semiconductor Factory

Jan Campbell, Qizhi He, Howie Yang, Martin Ivie,
John Gibbon, Darrel Lupo, Dario Nappa, Jerry Beene

TriQuint Semiconductor Product Sector
Compound Semiconductor Texas
500 W. Renner Rd Richardson, Texas 75080
Phone: 972-415-3218 Fax: 972-994-5768 Email: jan.campbell@tqs.com

Key Words; World Class Manufacturing

Abstract

This paper describes the steps used in addressing a final visual yield loss in a Compound Semiconductor process. These visual defects also have some electrical as well as assembly implications associated with them, thus they cannot be easily dismissed. Using a structured approach to problem solving and by isolating the device and defect types, studying the process flow, performing is/is not analysis as well as using quality tools such infinity diagrams and inter-relationship diagraphs helped in identifying the phenomena which resulted in identifying key process improvements that led to recovering the yield loss.

INTRODUCTION

TriQuint Texas inspects 100% of its wafers at Final Outgoing Inspections (FOI). At FOI there was a significant yield loss due to in-line defects caused by processing issues at previous steps (see Fig. 1). Isolating the defects and implementing in line inspections to discover where these occurred had to be part of a detailed plan carefully implemented since adding any such step is non-value added.

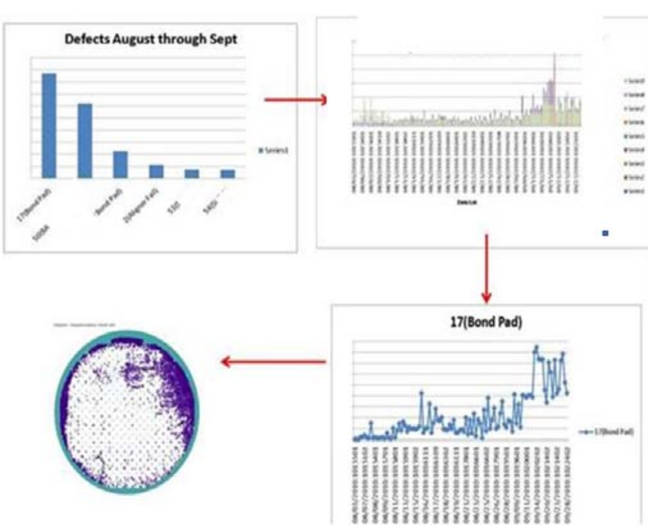
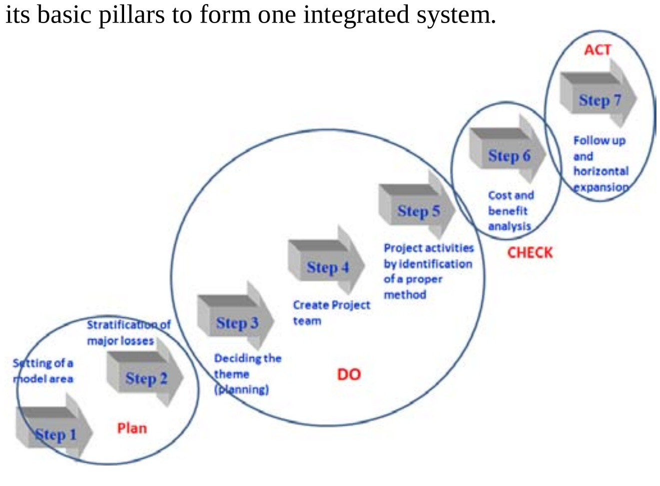


Fig. 1: Yield Loss Trends at the start of the project

The approach used on this project was part of a Focused Improvement (FI) seven-step process first introduced by Professor Yamashina to Japanese and European Manufacturers as part of a project to implement World Class Manufacturing (WCM) techniques to combat the rise of low-cost Asian manufacturers (see Fig. 2). WCM is essentially an extension of Total Product Management (TPM) where other concepts such as safety, environment, logistics/customer services, quality control, people development and cost deployment have been included with its basic pillars to form one integrated system.



Source: Professor Yamashina

Fig. 2: FI

Focused Improvement is an approach that roughly follows the Plan, Do, Check, Act cycle (PDCA) approach to process improvements, but it is much more, in that it can be used to solve problems in all areas of a company.

In this project studying the process flow, using Is/IS Not Analysis to identify key areas in the process to study, as well as implementing in-line data collection points resulted in identifying the phenomena (Who, What, When, Where, Which and How) and implementation of permanent corrective action.

DEFINING THE PHENOMENA

At FOI, there were many defect categories, but by Pareto charting defect types and deciding which defect to address through Impact, Cost, and Ease Analysis (ICE) the team was able to focus its efforts on the highest yield loss category. The next step was to understand the trend of the defect under study, was it common cause variation or special cause variation, was it getting worse, steady or was it getting better? This part is useful in determining the problem statement.

Definition of the phenomena requires several important steps including identifying who, what, when, where, which and most importantly how the defect occurs. This is referred to as the 5W and 1H approach. Without clear understanding of the how, permanent corrective action is not often achieved.

Conducting a Is/Is not approach will often aid in the discovery of the 5W's and sometimes even the 1H, however for complex issues more advance tools are needed to discover the 5W's and 1H.

Discovering the 5W's

1) Which is the defect, special cause or common variation?

One of the greatest mistakes made is treating special cause variation and common variation the same. Quite often, when yield excursions surface, panic and illogical reactions occur to address the issue, while this is normal, it often leads to valuable resources being diverted away from other focused activities. The other extreme is also very possible and that is, nothing is done at all.

In Fig. 1, the upper left graph (defects August through Sept) indicated that the pad residue defect was approx. equal to its historical average. If only this Pareto chart was studied, it might not have been noticed that the defect was trending up and the reaction might have been to do nothing at all. However, as can be seen from lower right graph in Fig. 1, there was a turn on, which indicated that something had changed in the process, and the cause of this "turn on" had not gone away. This indicated that the problem was related to a special cause.

2) Where is the defect occurring?

The defect was first discovered at AOI inspection, however at this point the resin cavities are present and rework is not possible. The defect was seen only on the Au bond pads. It occurred on the outer edge of the wafer. The severity and the location of the defect can be seen in Fig. 3:

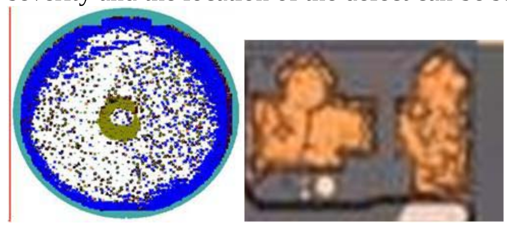


Fig. 3: Severity and Location of Defects

Determining where in process the defect was first occurred proved to be difficult and led to a segmented in-line defect monitoring program. Since the defect occurred on the pad, the first logical spot was to perform inspection prior to the pad formation and after the formation of the pad, after the etch process, and after the process. After several lots were inspected at these steps, a precursor "staining" of the bond pad was noted after the etch process with the problem still most easily detected after the resin encapsulation process. Further analysis of the data led to the fact that this defect was occurring on one specific device type and not on another similar device type. This led to doing an Is/Is Not Analysis.

Is/Is Not Analysis

This is a good technique to pinpoint a problem by exposing when it does and does not occur. The questions help to organize existing knowledge and information about the problem. Using this technique first to identify the problem can help focus additional problem analysis.

This tool can be as powerful as one makes it, driving data collection, material analysis, process flow comparisons and to discover the 5W's.

Studying the process flows for the two products and understanding how they vary using an Is/Is Not Analysis (see Fig. 4) was beneficial in isolating the area where the root cause could occur.

Comparing the difference in the process flows between the two products verified where the team should be looking.

Device A	Device B
Patterned Opening Etch	Patterned Opening Etch
Deposition of PAD metal	Deposition of PAD metal
Patterned Etch	Un-Patterned Etch
Un-Patterned Etch	Patterned Etch
Resin Encapsulation Process	Resin Encapsulation Process
Final Outgoing Inspection	Final Outgoing Inspection

Based on the comparison of product types, it was believed that there could be a complex residue remaining on the wafers after the patterned etch on Device B. This same complex residue was assumed to be removed on Device A by the un-patterned etch prior to resin encapsulation patterning. To verify this, wafers from Device B were pulled after the post etch process ash step and examined using a SEM. In Fig. 5, a defect is already visible using the SEM; however it was not seen under normal microscopy at this stage.

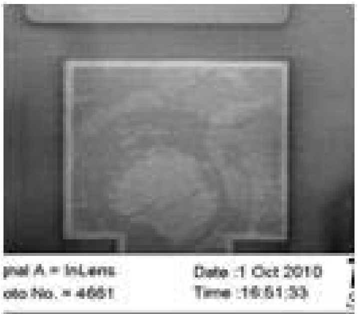


Fig. 5: Pad Residue Defect

The where was clearly identified at this point in the process, occurring after Ash in the patterned etch route.

3) What is the Defect?

Several high mass suspected gold adducts (i.e. Au combined with C, H, N, O, S or other potential elements) were only detected from the defect pads.

a. The Au adducts could have formed during the TOF-SIMS ionization process. In this case, they may be from Au combined with species relevant to the residue because they were not observed from any of the reference samples.

b. The molecular formulae for these species could not be determined because of their high mass and the numerous possible combinations of Au, C, H, N, O, S and other potential elements at the exact measured masses. Based on this additional information about our photoresists and/or other prior chemicals or chemical treatments that the wafer was exposed to should help identify these species.

c. Based on the small mass excesses measured for these species, they likely contain one or more Au atoms and were not purely organic in nature. It is possible that they contained another metallic species other than Au, but Au was the most likely candidate.

4) Who

There was no trend that indicated that this was operator or shift dependent.

5) When does the Defect occur?

The defect has appeared randomly at FOI, but at such a low level that it was not given priority. There was a clear turn on in August of 2010, in which the defect stayed at higher levels of yield loss. We examined the line for hardware changes that occurred during this time period. Trend charts were also examined that might indicate unintentional process shifts in related tools. In Fig. 6 the turn on date is displayed.

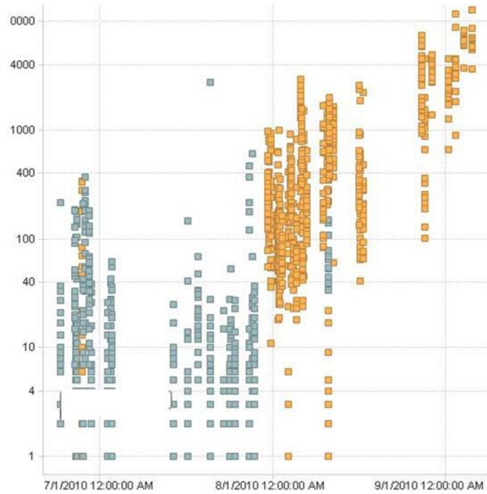


Fig. 6 Turn on Dates

Although the defect does not appear visually until it is processed through the resin encapsulation process, based on the SEM analysis, the defect occurs after the patterned etch resist strip

6) How does the defect occur?

This is always the most difficult part of a focused improvement effort. Using a structured approach often results in a better understanding of the problem which in turn leads to corrective action.

<u>Etch Tool</u>

Etching of the active devices is a pattern etch using resist to protect the areas that are not etched. The etch removes undesired material.

<u>O2 Matrix Asher</u>

Once the etching is complete the wafer is stripped of the photo resist using high temperature O2 plasma.

<u>Strip Chemistry</u>

The ash is followed by a generic wet strip that is Tetramethylammonium hydroxide (TMAH) based

<u>Resin encapsulation Step</u>

This step uses a resin made of a three component system, cyclopentanone, resin and a photo acid generator (PAG).

The resin is coated, exposed and developed. After this masking step the wafers are processed to FOI. At this point, the defect now is visible under an optical microscope.

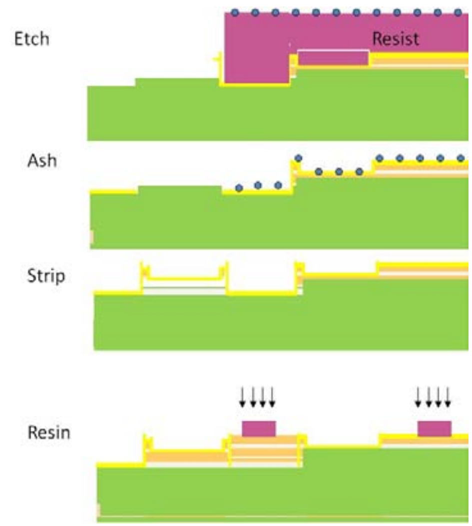


Fig. 7: Residue Formation Mechanism.

It was hypothesized that the material sputtered from the etch tool during the patterned etch reacts with the negative resist in the ash leaving a residue which adheres to the bond pads. This complex residue reacts with the unexposed resin on the bond pads and leaves residue after develop clearly seen in the Rudolph (see Fig. 7)

EXPERIMENTAL

To test the theory the defect was a result of this complex residue formation, a production lot was split into four splits (table 1)

Test #	Process Parameters
1	Short Ash/ Wet Strip/SRD/Scrub
2	Wet Strip/SRD/ short Ash/Scrub
3	Long Ash/ Wet Strip/SRD/Scrub
4	Wet Strip/SRD/SLong Ash/Scrub

TABLE 1: TEST SPLITS

RESULTS

The wafers were processed through resin patterning and inspected using a Rudolph In-Line Inspection Station. The control group (test 1) exhibited the defect with a yield loss of that had been seen in recent weeks. In test two, the strip and ash were reversed and the defect did not occur, but there were residue defects from the wet strip bath. In test three, the only difference was to increase the ash time, with additional exposure to O2 plasma increased visual defects as can be seen in on the right map in Fig. 8

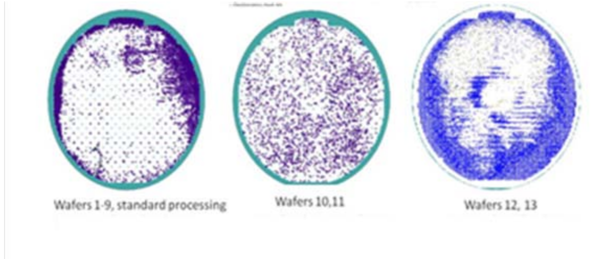


Fig. 8: Defect Maps of Splits

This testing was reproduced several times, but with the scrubber step removed and a two-step wet strip implemented. The result of this implementation eliminated the defect rate from this process step

PHENOMENA STATEMENT:

The defect occurs only on one product type, it occurs on the edge of the wafer and only on the bond pads. It is first seen after etching the resonators. It is not shift or operator related. The trend was increasing to the point that significant loss in yield occurred. During the etch process material is sputtered and deposits on the surface of the wafer as well as on the resist, as the resist is stripped away in the asher, the material cross links with the resist on the surface of the bond pads. In subsequent processing steps additional exposure to O2 plasma further enhances this phenomenon. In the resin process, the resin over the bonding pads becomes attached to this complex (resin cross links easy to the metals and its oxides when processed through the high temperature photo process) and decorates the defect making it visible optically.

CONCLUSIONS

A structured approach to problem solving resulted in quick resolution to significant yield loss. Further this project highlighted the need for a designated in-line defectivity group which can quickly recognize defects and put corrective actions in place before it impacts the customer

ACKNOWLEDGEMENTS

The authors would like to thank the following people Mortensen (Zych), Donna; Isom, Harold; Wilson, Randy; Maldonado, Daniel; Martin, Jarrett; Avrit, Brad; Carter, Bryson; Griffin, John; Milam, Vicki; Faraboni, Steve; Celli, Francis, McClure, Mike

REFERENCES

[1] Yamashina, Hajime from the Department of Precision Engineering, Graduate School of Engineering, Kyoto University

[2] Poole, Clive Kaizen Consultancy and Training Services (KCTS)